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ECONOMICS OF CROP DIVERSIFICATION OPPORTUNITIES FOR THE BROWN AND DARK BROWN SOIL ZONES OF SASKATCHEWAN

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Economics of Crop Diversification Opportunities for the Brown and Dark Brown Soil Zones of Saskatchewan

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a) Abstract/Summary:

Low prices for cereal grains and rising input costs, coupled with changes in government policies and programs (e.g., grain transportation, farm safety net programs), development of new markets and value-added opportunities, and growing concerns about soil and environmental degradation are stimulating significant change in land use practices throughout western Canada. Producers, particularly in the Brown and drier parts of the Dark Brown soil zones, have begun to extend and diversify their crop rotations, becoming less reliant on summerfallow and monoculture cereal cropping. The areas planted to crops such as canola, linola, mustard, field pea, chickpea and lentil are expanding dramatically in recent years, often into new or non-traditional production areas. The use of minimum and zero tillage management practices are becoming integral components of these newer production opportunities. These changes in land use practices are expected to continue, and perhaps grow in future years.

For these newer cropping systems to be sustainable in the long-term, however, they must: (i) be technically or agronomically feasible (i.e., suited to the soil and climatic conditions of the area, practical to implement, and capable of producing acceptable grain yields and quality); (ii) ensure that the quality of the soil, water, and air resources are maintained or enhanced; and (iii) be economically viable. This study focused on the latter aspect. We examined some of the main economic factors influencing producers' choices of these newer crop and soil management production systems for the Brown and Dark Brown soil zones, with particular emphasis on the risk management attributes of these diversified cropping systems. The study determines and compares the economic merits and relative riskiness (both production and market) of producing chickpea, field pea, lentil, mustard, canola, and flax with spring wheat or barley when grown on chemical fallow and zero-till stubble for various plausible product price scenarios. The study draws on data from three completed field experiments, one conducted at the Semiarid Prairie Agricultural Research Centre (1992 to 1996), a second on a producer's field at Congress (1994 to 1996), and a third conducted at the Scott Experimental Farm also during the 1990s. These data were extended with use of a STELLA® model, to elucidate the short-term and the longer-term economic and environmental impacts of these newer cropping systems.

Our findings indicate that under current market conditions, risk averse producers in the Brown soil zone would typically choose either the 4-year Fallow-Chickpea-Wheat-Wheat rotation or the 5-year Durum-Chickpea-Mustard-Wheat-Lentil rotation. In the Dark Brown soil zone, risk averse producers would choose the 4-year Canola-Wheat-Lentil-Wheat rotation.

b) Executive Summary:

This study uses STELLA as a modeling tool to measure the dynamic relationship between soil quality and the economic performance of a series of monoculture and diversified crop rotations in the Brown and Dark Brown soil zones. The framework developed in this research incorporates a number of characteristics of the agricultural system:

- The model simulates a series of "alternative" rotations that incorporate less common crops and management strategies for each target region, thereby facilitating an evaluation of the value of soil quality changes under new and alternative cropping and soil management methods.

- The model explicitly allows for increasing soil quality [increasing soil organic carbon (SOC) stocks] under the various annual crop management regimes.

- The model does not incorporate a profit maximizing objective function, but explicitly allows for the substitution of fertilizer for changes in the supply of organic nutrients provided by the soil.

- The analysis evaluates the relative economic and environmental performance of different crop rotations by comparing changes in simulated indicators during short-run and long-run simulations.

- The model and analysis provides output that is regionally appropriate by incorporating the specific biophysical (soil texture, depth of topsoil, precipitation, solar energy) and economic (input costs, output prices) characteristics of the target areas.

As a result, the model facilitates a "systems level" analysis of the long-term value, in economic and sustainability terms, of SOC changes as influenced by alternative crops and soil management alternatives.

Simulations were performed based on a one-year time step with each simulation comprising a 60-year period. The model includes stochastic weather parameters. In order to capture the statistical characteristics of the simulation data, (i.e., the probability distributions of net returns for each cropping system) 100 separate runs were performed.

The environmental model was developed around a series of annual crop rotations for the Brown and Dark Brown soil zones. A "conventional" rotation was simulated to represent a traditional rotation commonly used in each of the soil zones. These rotations served as the benchmark management practices in the analysis and represent diversity level one. The alternative rotations were selected to be agronomically and technically suitable for the target regions and included pulse and oilseed crops in addition to the traditional cereal crops. Diversity level two rotations included either a pulse or an oilseed crop, and diversity level three contained at least one crop from each of the cereals, oilseeds and pulse categories. The model simultaneously simulated all rotations in a given soil zone to ensure that weather patterns were identical for all production systems.

The economic model was parameterized using output prices and cost of production data appropriate for the modeled crops in the Brown and Dark Brown soil zones of Saskatchewan. Output prices were based on 2002 farm gate commodity price estimates published by Saskatchewan Agriculture and Food.

Production costs include the variable cost items such as seed, chemicals, nitrogen fertilizer, phosphorus fertilizer, sulfur fertilizer, fuel, transportation, machinery repair, custom work, hired labour, crop insurance, and interest costs and utilities. Other cost items include fixed machinery costs, machinery depreciation, building costs, property taxes and insurance. Chemicals, fuel, and other costs were held constant during the simulations with values based on average costs for the specific crops and management schemes in the respective soil zones. Operator labour and land costs were excluded since these would be similar across all rotations. Nitrogen and phosphorus fertilizer rates were endogenous variables based on constant fertilizer costs ($0.58/kg and $0.66/kg for actual N and P_2O_5, respectively) and as determined by the environmental model. Transportation costs include freight, trucking, dockage and elevation charges for the specific crop, with the specific costs for the crop and rotation being determined by the simulated crop yields.

In the Brown soil zone, production costs increased as additional crops were added to the rotation. The lowest cost rotation was Fallow-Wheat-Wheat ($181/ha) and the highest cost rotation was Durum-Chickpea-Mustard-Wheat-Lentil ($288/ha). In general, wheat, durum and mustard were the lowest cost crops within the rotations. Pulse crops had the highest costs led by chickpea, lentil and field pea reflecting the high seeding rates and increased chemical use required for these crops. In the Dark Brown soil zone, production costs were lowest for Fallow-Barley-Wheat ($209/ha), Fallow-Canola-Wheat-Barley ($237/ha) and Fallow-Wheat-Lentil-Wheat ($242/ha). Each of the remaining six rotations had similar production costs ranging between $275/ha and $292/ha. Wheat had the lowest production costs ($264/ha), followed by field pea, barley, flax and canola. The highest cost crop in the Dark Brown soil zone was lentil ($325/ha) due to higher seed and pesticide costs.

On a complete rotation basis in the Brown soil zone over a 60-year simulation period, Fallow-Chickpea-Wheat-Mustard-Wheat and Durum-Chickpea-Mustard-Wheat-Lentil had the highest average annual net returns at $137/ha and $124/ha, respectively. Fallow-Mustard-Wheat-Wheat had the lowest net return at $46/ha. In the Dark Brown soil zone, Canola-Wheat-Lentil-Wheat had the highest average annual net return at $185/ha, and Canola-Wheat-Barley-Field Pea and Canola-Barley-Field Pea-Wheat had the lowest average annual net return at $72/ha and $74/ha, respectively.

In the Brown soil zone, an increase of one standard deviation in the price of all cereal crops (wheat and durum) above the base levels (prices for all other grains held constant) increased the mean net return of all rotations, with the relative improvement in profitability being greatest for the monoculture cereal rotation ($106/ha higher) . When cereal prices were decreased by one standard deviation, net returns decreased for all rotations, but the relative rankings remained unchanged. Increasing mustard prices increased average annual net returns for all rotations that included mustard and improved the ranking of Fallow-Mustard-Wheat-Wheat (increased net returns 43%) above that of Fallow-Wheat-Lentil-Wheat (at base price levels). Increasing pulse prices (field pea, chickpea and lentil) favoured rotations that included lentil due to lentil having the highest standard deviation for price of all the pulses. In general, increasing the pulse prices increased net returns by 33% to 39%.

In the Dark Brown soil zone, increasing the price of cereals (wheat and barley) increased the mean net returns of all rotations and improved the ranking of Fallow-Wheat-Lentil-Wheat to number one from number two. Decreasing cereal prices resulted in negative returns for the Fallow-Barley-Wheat rotation, but did not change the ranking of the rotations. Increasing oilseed prices (canola and flax) increased the mean net return of rotations with at least one oilseed from 29% to 42%, and increased the ranking of the Canola-Wheat-Field Pea rotation to number two from number four. Decreasing pulse prices (field pea and lentil) did not change the ranking of the rotations. However, increasing pulse prices improved the ranking of Canola-Wheat-Field Pea to number one from number two.

Simulated SOC stocks increased under all zero-till managed rotations in both the Brown and Dark Brown soil zones. In the Brown soil zone SOC stocks increased by 0.52-0.77 t/ha/yr, while in the Dark Brown soil zone the increases were 0.84-1.08 t/ha/yr.

Overall, our findings suggest that under current market conditions, risk averse producers in the Brown soil zone would choose either the 4-year Fallow-Chickpea-Wheat-Wheat rotation or the 5-year Durum-Chickpea-Mustard-Wheat-Lentil rotation. In the Dark Brown soil zone, risk averse producers would choose the 4-year Canola-Wheat-Lentil-Wheat rotation.

Table of Contents

Abstract/Summary	2
Executive Summary	3
Table of Contents	6
Introduction	7
Literature Review	7
Economic Models Of Soil Conservation	7
Simulation Models	8
Production Based Simulation Models	9
EPIC	9
STELLA	9
Materials and Methods	10
Model Specification	10
Economic Analyses	12
Results and Discussion	14
Simulation Results	14
Yields	14
Production Cost	14
Net Returns	16
Financial Risk	20
Soil Quality	22
Conclusions	24
References	25
Appendix A	28
Appendix B	38
Personnel	40
Equipment	40
Project Development Materials	40
Project Photos	40
Acknowledgement	40
Expense Statement	Attached

Introduction

Following the above average rainfall years of the mid to late 90's, the semi-arid prairie region of western Canada has seen precipitation levels subside, giving way to severe moisture deficits and wide spread drought conditions. These recent dry conditions have significantly reduced yields and potential farm revenues, leaving producers with the arduous task of managing their crops to make the best use of available moisture. Crop types and rotation selections are important management tools that allow producers to use available moisture more efficiently. This paper investigates the profitability of competing crop rotations in the Brown and Dark Brown soil zones of Saskatchewan.

Literature Review

Economic Models of Soil Conservation

Cropping decisions are influenced by an array of dependent and independent factors, including commodity and input markets, government programs, changing technology, and land management techniques. In addition, producer's production decisions are complicated by interrelationships between these variables and the dynamic nature of agricultural production itself. Alternative cropping system models must consider multiple farming system attributes and the entire set of decision variables. This methodology is the concept of systems analysis[1].

The systems approach takes into consideration variables, which are controlled by the decision maker, and the uncontrollable or stochastic variables that account for the uncertainty in farming. The technique of simulation has proven to be a powerful method for modeling complex systems involving risk and uncertainty. Simulation is the method of studying the behaviour of a system over time. Simulation requires two processes. The first process is development of a model designed to simulate a real situation or system. The second process incorporates the model into a series of experiments or simulations. Simulation techniques are useful because they can be adapted to incorporate dynamic as well as stochastic elements of the system. Halter, Hayenga and Manetsch (1971), describe simulation models as having three components:

1. a difference equation of the system model describing the state of the system and subsequent performance at discrete points in time;

2. an equation which allows a comparison of the performance of the model with a real situation; and

3. an equation relevant to the experimentation stage of the simulation process. This enables the researcher to observe the performance of the system over time and under several policy changes.

Simulation is able to accommodate most types of modeling techniques, including regression models, mathematical programming models, identities, and probability

[1] A system may be broadly defined as a collection of interrelated components or elements with a purpose. The study of systems is referred to as systems analysis, (Saliba, 1983).

sampling. Simulation models allow for the investigation of numerous competing alternatives, and with the aid of increased computational power, replications involving numerous trials are easily performed.

The main problem of simulation revolves around the construction of the model. Over simplification of the model could cause the results to be trivial, while excessively complex models may become prohibitively cumbersome. Therefore, model specification is pivotal in the acquisition of meaningful results.

Simulation Models

The degree of complexity involved in developing a simulation model can vary greatly, but more vital to the building of a model is the relevance of the included variables. Saliba (1983), suggests that research in the area of farm-level soil conservation economics can be divided into four categories:

1. Short-run farm budget simulation;
2. Analyses of farm business characteristics and producer conservation decisions;
3. Analyses of farm tenure characteristics; and
4. Intertemporal modeling.

Short-run farm business simulation techniques often use farm management models to simulate various production strategies. This method of simulation can be used to determine the costs and benefits of varying production decisions on the quality of the soil by altering the control variables, which include: crop rotations, tillage techniques, and fertilizer and chemical usage. These models tend to be static in nature and do not allow for feedback between variables over time. Thus, they do not account for the intertemporal effects of soil degradation. Weisensel (1988) states that this issue is especially important since the yield-soil depth relationship is generally believed to be non-linear, implying that the cost of soil erosion may be increasing over time.

Saliba's second category for farm-level soil conservation economics is also static in nature. The analyses of farm business characteristics, and producer conservation decisions are useful because of its ability to identify key variables that affect producers' conservation decisions. This category is characterized by statistical analyses that can be used to identify how producer's attitudes toward soil conservation change over time.

The third category is analyses of land tenure characteristics. This involves analyzing and comparing land tenure conservation practices of landowners and that of land renters. Theoretically, landowners should have a greater tendency to use or invest in soil conservation techniques than land renters, because the long-term benefits of soil conservation would accrue to the landowner through increased land values.

Saliba's fourth category is intertemporal modeling. Intertemporal modeling of soil conservation decisions over time can be performed in two ways. The first method uses optimal control theory or dynamic programming. The second method uses short-run farm budget simulators linked to provide feedback to the model to create multiyear simulations. The intertemporal approach allows the model to capture the impacts of various farming systems on soil quality over time. Being able to capture the effects of different farming systems over time enables the model to track levels of soil productivity throughout the life of the simulation. In addition, intertemporal models can better simulate the decision making process of producers by allowing successive decisions to build on the outcomes of previous decisions. This feedback mechanism is an important feature when developing farm-level simulation models since producers make investment

decisions based on specific planning horizons. Lastly, intertemporal models are used to relate information about farm tenure and land characteristics.

Production Based Simulation Models

Erosion Productivity Impact Calculator (EPIC)

EPIC is a comprehensive production based simulation model designed to simulate crop development for predetermined crop varieties (Wall, 2000). During the simulation process, EPIC calculates and records the effects of erosion and uses the events to adjust the productivity of the soil resource. EPIC is comprised of two main modules. The first module consists of a physically based component used in the simulation of plant growth, erosion and other related biological, physical production processes. The second module is an economic calculator used in the assessment of erosion costs and determining optimal management strategies.

The EPIC model functions to determine the relationship between soil erosion and soil productivity. Originally, EPIC was only available for erosion/productivity simulations in the U.S.A., but it has now been validated and used in Canada for the same purpose (Wall, 2000). EPIC continuously simulates the processes associated with erosion in a daily time step and is capable of simulating hundreds of years into the future. The physical component module in EPIC includes hydrology, weather simulation, erosion-sedimentation, nutrient cycling, plant growth, tillage, and soil temperature. EPIC is designed to model the relationship between soil erosion and soil productivity by simulating the processes involved using the weather generated from an area's historical weather data. The erosion/productivity relationship for a cropping system is reflected in the crop yields for a particular soil type and topography. Further, EPIC allows different cropping systems to be compared using the same weather sequences for all alternative cropping systems being compared.

STELLA

The STELLA simulation model is comprised of environmental and economic sub-models (see Appendix A for a detailed description). The environmental component simulates soil quality through the ability of the soil to provide nitrogen, phosphorus and water for crop growth, and estimates crop yields based on the soil function at a given point in time. A simple economic component calculates rotation scale costs and revenue based on yield and input requirement data provided by the environmental model. To simulate target ecodistricts, the model is parameterized using appropriate biophysical data representative of the regions. Three categories of data are used: (1) soil type – soil texture, soil thickness; (2) climate – growing season precipitation, over winter precipitation, growing degree days, mean daily temperature; and (3) initial soil stocks – soil surface residue, soil nitrogen, soil phosphorus, soil organic carbon (SOC) content. Crop production is simulated based on the concept that maximum potential yield is achieved if all plant growth requirements are optimal. The essential plant growth requirements in this framework are nitrogen, phosphorous and water. The economic component calculates profit for the selected rotations in each year of the simulation. Because at each time step the environmental model calculates yield for a single crop in

the rotation sequence, the rotation scale profits are calculated as a rolling sum of profits for all crops in the rotation.

Materials and Methods

Model Specification

The environmental sub-model was developed around a series of annual crop rotations for the Brown and Dark Brown soil zones. A "conventional" or traditional rotation was included in each soil zone. These rotations served as the benchmark management practices in the analysis and represent diversity level one. The alternative rotations were selected to be agronomically and technically suitable for the target regions and included pulse and oilseed crops in addition to the traditional cereal crops. Diversity level two rotations included either a pulse or an oilseed crop, and diversity level three contained at least one crop from each of the cereals, oilseeds and pulse categories. A complete list of the rotations simulated for the Brown soil zones are shown in Table 1 and for the Dark Brown soil zone are shown in Table 2. The model simultaneously simulated all rotations in each soil zone to ensure that weather patterns were identical for all production systems. The simulation runs were replicated 100 times using randomized weather sequences (typical of each region) spanning a 60-year time horizon.

Environmental Model

Within the environmental sub-model, crop production potential is determined by soil quality, as represented by the ability of the soil to provide nutrients and water for crop growth. Soil quality is an endogenous variable that was determined by the study areas specific soil texture and climatic parameters as well as the cropping practices employed within the simulated rotations, including the influence of the crop varieties grown and method of tillage management used. To estimate crop yields the main function of the environmental model is to simulate the amount of nitrogen, phosphorus and water provided by the soil at each time step under each crop rotation. The quantities of these crop growth requirements are used to determine the input sufficiencies (Table 3). An important driver in the environmental model is the stock of SOC. In general, soils with larger SOC stocks have greater water holding capacity and greater supplies of organic soil nitrogen and phosphorus (Acton and Gregorich 1995; Boehm and Eidman 1983). The stock of SOC at a point in time reflects the initial stock in the soil and the subsequent difference between the rate of addition of crop residue to the soil and the rate of organic matter loss as CO_2 due to microbial decomposition and respiration. The quantity of crop residue added to the soil at a given time is a function of the crop variety and crop yield.

The level of spatial aggregation in the model is the ecodistrtict. An ecodistrict is an area defined by landform, vegetation and soil that is relatively homogeneous in these characteristics compared to the surrounding landscape (Acton et al. 1998). The biophysical characteristics used in the model to simulate crop production in the Brown and Dark Brown soil zones are presented in Table 4.

Table 1. Crop rotations by diversity level for the Brown soil zone.

Diversity	Rotation	Abbreviation
Diversity level 1	Fallow-Wheat-Wheat	F-W-W
Diversity level 2	Fallow-Mustard-Wheat-Wheat	F-M-W-W
	Fallow-Wheat-Lentil-Wheat	F-W-L-W
	Fallow-Chickpea[a]-Wheat-Wheat	F-CP-W-W
	Fallow-Durum-Field Pea-Durum	F-D-FP-D
Diversity level 3	Fallow-Mustard-Wheat-Lentil-Wheat	F-M-W-L-W
	Fallow-Mustard-Wheat-Chickpea[a]-Wheat	F-M-W-CP-W
	Fallow-Chickpea[a]-Wheat-Mustard-Wheat	F-CP-W-M-W
	Durum-Chickpea[a]-Mustard-Wheat-Lentil	D-CP-M-W-L

[a]Chickpea type is Kabuli (large size).
[b]Mustard type is Brown.

Table 2. Crop rotations by diversity level for the Dark Brown soil zone.

Diversity	Rotation	Abbreviation
Diversity level 1	Fallow-Barley-Wheat	F-B-W
Diversity level 2	Canola[a]-Wheat-Field Pea	C-W-FP
	Field Pea-Wheat-Barley	FP-W-B
	Fallow-Canola[a]-Barley-Wheat	F-C-B-W
	Fallow-Wheat-Lentil-Wheat	F-W-L-W
Diversity level 3	Canola[a]-Wheat-Lentil-Wheat	C-W-L-W
	Canola[a]-Wheat-Barley-Field Pea	C-W-B-FP
	Canola[a]-Barley-Field Pea-Wheat	C-B-FP-W
	Flax-Barley-Lentil-Wheat	FX-B-L-W

[a]Canola type is Argentine type.

Table 3. Parameters used to initialize the environmental sub-model.

Crop	Ymax (t/ha)[a]	Harvest Index (kg residue/kg grain)[b]	N content of residue (g/kg)[c]	100% N sufficiency (kg/ha)[d]	P export (kg/t of grain)[e]	100% P sufficiency (kg/ha)[f]
Spring Wheat	3.80	2.20	2.07	95	4.10	40
Durum	3.80	2.20	2.07	95	4.10	40
Mustard	3.00	2.20	1.43	115	10.00	44
Barley	6.00	2.20	2.07	100	3.60	31
Canola	3.10	2.20	1.43	115	10.00	44
Flax	3.40	1.80	1.43	115	4.80	42
Peas	5.00	1.20	2.36	40	5.00	20
Lentils	2.50	1.20	2.36	20	5.20	20
Chickpea	3.00	1.20	2.20	30	5.00	30

Table 4. Biophysical characteristics of the study regions.

Region	Temp (°C)	May to August 30 Year. precip. (cm)	September to April 30 Year Precip. (cm)	Growing degree days	Soil texture
Brown	20	19	17	1460	Clay loam – loam
Dark Brown	18	19	21	1440	Clay loam

The quantity of nitrogen available to the crop at any time is the sum of soil nitrogen plus fertilizer nitrogen. Nitrogen fertilizer is assumed to be available in the year of application only. Total nitrogen fertilizer inputs are constrained in the model by assuming that soil nitrogen plus fertilizer nitrogen cannot exceed 100% sufficiency for each crop (Table 3). Nitrogen fertilizer rates are further adjusted based on available soil water at the beginning of the growing season. For example, the quantity of nitrogen fertilizer is scaled back from optimum rates if spring soil moisture conditions were less than 50 percent of average. This relationship is based on the assumption that poor soil moisture conditions will cause producers to be less willing to invest in fertilizer inputs.

The quantity of available phosphorus is determined by the rate of phosphorus release from mineral, organic and fertilizer sources minus the amount of phosphorus exported with grain produced in the previous year.

Total water soil water is based on the sum of precipitation received during the growing season and snow-melt equivalent precipitation (non-growing season precipitation) (Table 4). Within the model, precipitation is a stochastic variable with yearly growing season and non-growing season quantities being randomly selected from gamma distributions that were created based on long-term measured data from the specific study area (Swift Current - Brown soil zone and Scott - Dark Brown soil zone). The proportion of total precipitation that is available to the crop in each time step is determined by the infiltration rate, recharge rate, and water storage capacity of the soil (Appendix A). Precipitation received in non-growing season months enters the soil as run-off at one half of the infiltration rate, based on the assumption that overwinter recharge of stubble is equivalent to about half of the snow water received over the winter. Soil water storage capacity determines the water available for crop growth. The water storage capacity of the soil is a function of soil texture and the SOC content of the soil as determined by the Universal Soil Loss Equation (Wischmeier and Smith 1978).

Economic Analyses

The economic model was parameterized using output prices and cost of production data appropriate for the specific crops in the Brown and Dark Brown soil zones of Saskatchewan (see Appendix B for details). Output prices were based on 2002 farm gate commodity price estimates published by Saskatchewan Agriculture and Food (Table 5). All rotations were assumed to operate using zero-tillage management methods. Cost of production data were based on Saskatchewan Agriculture and Food 2002 Crop Planning guides for the Brown and Dark Brown soils as well as the Specialty Crops Planning Guide for 2002 (Saskatchewan Agriculture and Food (2002a, 2002b, 2002c).

Table 5. Farm gate output prices for crops.

Crop type	Brown Soil Zone		Dark Brown Soil Zone	
	Price	Standard Deviation	Price	Standard Deviation
	----------($/t)----------		---------($/t)---------	
Wheat	172	30	172	30
Durum	176	51	-	-
Barley	-	-	106	31
Field Pea	169	27	169	27
Chickpea	550	52	-	-
Lentil	374	58	374	58
Mustard	311	105	-	-
Canola	-	-	268	67
Flax	-	-	275	62

Source: Saskatchewan Agriculture and Food (2002a), (2002b), (2002c).

Production costs include variable items such as seed, chemicals, nitrogen fertilizer, phosphorus fertilizer, sulfur fertilizer, fuel, transportation, machinery repair, custom work, hired labour, crop insurance and interest costs and utilities. Other cost items include machinery investment, machinery depreciation, building costs, property taxes and insurance. Chemicals, fuel, and other costs were held constant during the simulations with values based on average costs for the specific crops and management schemes in each soil zone. Expenditures on N and P fertilizers were endogenous variables based on constant fertilizer costs ($0.58/kg and $0.66/kg for actual N and P_2O_5, respectively) and application rates determined by the environmental model. Transportation costs include freight, trucking, dockage and elevation charges for the specific crop with the specific costs for the crop and rotation being determined by the simulated crop yields.

The economic performance of the nine crop rotations for the Brown and Dark Brown soil zones were analyzed on an annual basis. Each system was evaluated in regard to costs of production, net returns and riskiness. Net return was defined as gross income less total costs, including all cash costs (seed, fertilizer, pesticides, fuel, oil, repairs, crop insurance, property taxes, interest and miscellaneous items) and fixed costs (building and machinery investment and depreciation). Riskiness was assessed using stochastic dominance analysis (Goh et al., 1989) to compare the probability distributions of average annualized net incomes for groups of producers having low, medium and high risk aversion as defined by Zentner et al. (1992). Operator labour and land costs were excluded since these would be similar for all rotations. The performance of each cropping system was also evaluated for a range of product prices (representing one standard deviation lower than the respective base prices to one standard deviation higher than the respective base values) to test the sensitivity of the findings to changes in these price conditions. The economic performance results were expressed on a per hectare basis for both the complete rotation and for the individual crops within the respective rotations.

Results and Discussion

Simulation Results

The STELLA model's yield estimates (mean, maximum, minimum, standard deviation, and coefficient of variation) for each cropping system are shown for the Brown and Dark Brown soil zones in Tables 6 and 7, respectively.

Crop yields simulated by the model for the Brown soil zone (Table 6) were similar to ten year historic averages for the region, although the model tended to slightly overestimate durum, chickpea and spring wheat on fallow yields. Further, the simulated mustard, lentil and field pea yields were similar to the ten-year averages for the province as a whole (yield averages for the target region were not available)(Table 8).

In contrast, simulated yields in the Dark Brown soil zone (Table 7) were generally higher than the ten-year regional averages (Table 8). This can be explained by the fact that additional yield limiting factors including insects, disease, weed competition, and extreme weather events were not captured in the model. Therefore, the results for the Dark Brown soil should be considered to represent optimal economic and biophysical conditions.

Production Costs

Average costs of production for the nine crop rotations in each soil zone are shown in Appendix B. Costs of production for individual crops within each rotation are listed including the cost of chemfallow, which was used throughout the simulations.

In the Brown soil zone, production costs increased as additional crops were added to the rotation. The lowest cost rotation was F-W-W ($181/ha) and the highest cost rotation was D-CP-M-W-L ($288/ha). In general, wheat, durum and mustard were the lowest cost crops to grow. Pulse crops had the highest costs, led by chickpea, lentil and field pea reflecting the high seeding rates and increased chemical use required for pulse production. On the other hand, N fertilizer costs were lowest for pulse crops, intermediate for mustard, and highest for the cereals. On a complete rotation basis, N fertilizer costs were highest for F-M-W-W ($24/ha) followed by F-W-W ($20/ha), with F-W-L-W, F-D-FP-D and F-CP-W-W having the lowest cost for N fertilizer at about $10/ha. The D-CP-M-W-L rotation had the highest pesticide cost ($70/ha), primarily due to the high use of fungicides with chickpea. The rotation with the lowest pesticide cost was F-W-W ($35/ha).

In the Dark Brown soil zone, production costs were lowest for F-B-W ($209/ha), F-C-W-B ($237/ha) and F-W-L-W ($242/ha). Each of the remaining six rotations had similar production costs ranging from $275/ha to $292/ha. Wheat had the lowest cost of production ($264/ha), followed by field pea, barley, flax and canola. The highest cost crop in the Dark Brown soil zone was lentil ($325/ha) due to higher seed and pesticide costs. Nitrogen fertilizer costs were highest for the oilseed crops, followed by the cereals and then pulses. The rotations with the highest average N fertilizer cost were F-C-B-W, C-B-FP-W and FX-B-L-W at $26/ha. The rotations with the highest pesticide cost included lentil, (i.e. C-W-L-W and FX-B-L-W) and ranged from 66$/ha to $70/ha. The rotation with the lowest pesticide cost was F-B-W ($44/ha).

Table 6. Simulated crop yields for rotations in the Brown soil zone.

Rotation	Crop	Mean	Maximum	Minimum	Standard Deviation	Coefficient of Variation
		----------t/ha----------				(%)
F-W-W	Wheat on Fallow	2.24	3.71	0.77	0.85	38
	Wheat on Wheat	1.86	3.04	0.74	0.59	32
F-M-W-W	Mustard on Fallow	1.52	2.88	0.16	0.72	48
	Wheat on Mustard	1.71	3.16	0.69	0.74	43
	Wheat on Wheat	1.68	2.88	0.51	0.71	42
F-W-L-W	Wheat on Fallow	2.30	3.69	0.46	0.80	35
	Lentil on Wheat	1.33	2.18	0.69	0.46	35
	Wheat on Lentil	1.65	2.79	0.53	0.68	41
F-CP-W-W	Chickpea on Fallow	1.54	2.72	0.36	0.61	40
	Wheat on Chickpea	1.66	3.10	0.69	0.73	44
	Wheat on Wheat	1.69	2.86	0.54	0.69	41
F-D-FP-D	Durum on Fallow	2.35	3.60	0.48	0.76	32
	Field Pea on Durum	2.09	4.22	1.06	0.96	46
	Durum on Field Pea	1.76	2.86	0.56	0.65	37
F-M-W-L-W	Mustard on Fallow	1.39	2.73	0.19	0.91	65
	Wheat on Mustard	1.44	2.48	0.58	0.61	42
	Lentil on Wheat	1.30	1.97	0.77	0.42	32
	Wheat on Lentil	1.88	3.34	0.44	0.85	45
F-M-W-CP-W	Mustard on Fallow	1.47	2.84	0.22	0.92	63
	Wheat on Mustard	1.39	2.43	0.54	0.60	44
	Chickpea on Wheat	1.09	1.87	0.62	0.43	39
	Wheat on Chickpea	1.81	3.28	0.40	0.84	47
F-CP-W-M-W	Chickpea on Fallow	1.69	2.91	0.53	0.84	50
	Wheat on Chickpea	1.36	2.38	0.38	0.60	44
	Mustard on Wheat	1.04	2.16	0.53	0.63	61
	Wheat on Mustard	1.83	3.30	0.41	0.84	46
D-CP-M-W-L	Durum on Lentil	1.74	2.82	0.72	0.78	45
	Chickpea on Durum	1.12	2.36	0.30	0.69	62
	Mustard on Chickpea	1.03	2.17	0.27	0.64	62
	Wheat on Mustard	1.41	2.35	0.72	0.56	40
	Lentil on Wheat	1.59	2.52	0.43	0.61	38

Table 7. Simulated crop yields for rotations in the Dark Brown soil zone.

Rotation	Crop	Mean	Maximum	Minimum	Standard Deviation	Coefficient of Variation
		t/ha				(%)
F-B-W	Barley on Fallow	3.28	5.79	1.55	1.26	38
	Wheat on Barley	2.22	3.28	0.64	0.80	36
C-W-FP	Canola on Field Pea	1.21	2.50	0.37	0.65	54
	Wheat on Canola	2.00	3.42	1.00	0.69	34
	Field Pea on Wheat	2.39	3.91	0.79	0.90	38
F-C-B-W	Canola on Fallow	2.01	2.93	1.14	0.64	32
	Barley on Canola	2.51	4.81	0.92	1.22	48
	Wheat on Barley	1.73	3.19	0.60	0.85	49
F-W-L-W	Wheat on Fallow	2.88	3.88	2.05	0.65	23
	Lentil on Wheat	1.46	2.24	0.77	0.43	29
	Wheat on Lentil	1.68	3.05	0.57	0.80	47
FP-W-B	Field Pea on Barley	2.51	4.81	1.24	0.99	39
	Wheat on Field Pea	2.03	3.43	1.05	0.68	34
	Barley on Wheat	2.13	3.84	0.45	1.08	51
C-W-L-W	Canola on Wheat	1.72	2.61	0.82	0.44	26
	Wheat on Canola	2.13	3.42	1.22	0.76	36
	Lentil on Wheat	1.44	2.23	0.73	0.43	30
	Wheat on Lentil	1.70	3.08	0.59	0.80	47
C-W-B-FP	Canola on Field Pea	1.14	2.93	0.40	0.76	55
	Wheat on Canola	2.39	3.73	0.84	0.84	35
	Barley on Wheat	2.30	4.73	0.38	1.33	58
	Field Pea on Barley	2.27	3.78	0.62	0.92	40
C-B-FP-W	Canola on Wheat	1.62	2.50	0.71	0.44	27
	Barley on Canola	2.75	5.12	1.09	1.36	49
	Field Pea on Barley	2.09	4.02	1.01	0.84	40
	Wheat on Field Pea	1.73	3.13	0.60	0.81	47
FX-B-L-W	Flax on Wheat	1.57	2.36	0.84	0.36	23
	Barley on Flax	2.71	5.05	1.09	1.35	50
	Lentil on Barley	1.45	2.24	0.78	0.43	30
	Wheat on Lentil	1.70	3.08	0.59	0.80	47

Table 8. 10 year average historical grain yields.

Crop type	Brown Soil Zone	Dark Brown Soil Zone
	Yield	Yield
	----------(t/ha)----------	
Wheat	2.09	2.13
Durum	2.30	
Barley		2.62
Field Pea	2.06	2.06
Chickpea	1.39	
Lentil	1.31	1.31
Mustard	1.00	
Canola		1.40
Flax		1.31

Source: Saskatchewan Agriculture and Food, Agricultural Statistics 2000.

Net Returns

Tables 9 and 10 show the mean, maximum, minimum and standard deviation for annual net returns for individual crops within each cropping system. In the Brown soil zone, chickpea grown after fallow in the F-CP-W-W rotation and in the F-CP-W-M-W rotation had the highest average annual net returns at $491/ha and $539/ha, respectively. The highest annual net return was earned with chickpea in the F-CP-W-M-W rotation at $1219/ha, and the lowest was earned with wheat after lentil in the F-M-W-L-W rotation ($-146/ha).

In the Dark Brown soil zone, the highest average annual net return was earned with canola grown on fallow in the F-C-B-W rotation ($345/ha). The lowest average annual net return was earned with barley grown on wheat stubble at $-70/ha. The highest annual net return was obtained with wheat grown on field pea stubble in the C-W-FP-W rotation ($659/ha), and the lowest was obtained with barley grown on wheat stubble in this same rotation ($-265/ha).

On a complete rotation basis, net returns (over the 60-year simulation period) were highest for F-CP-W-M-W and D-CP-M-W-L in the Brown soil zone at $124/ha and $107/ha, respectively. F-W-W had the lowest average net return at $54/ha (Table 11). In the Dark Brown soil zone, C-W-L-W had the highest average annual net return at $122/ha and F-B-W had the lowest ($34/ha) (Table 11).

A change in grain price will have its greatest impact on those cropping systems that devote a high proportion of the land area to that crop whose price has changed, and/or to those tillage methods that foster a yield advantage for that crop type (Zentner et al. 2002). In the Brown soil zone, an increase in grain price of one standard deviation for all cereal crops (wheat and durum) above the base levels (prices for all other grains held constant) increased the mean net return of all rotations, but the relative improvement in profitability was greatest for the monoculture cereal rotation ($39/ha higher) (Table 11). Leaving the F-M-W-W rotation as the least profitable of all nine rotations. When cereal prices were decreased by one standard deviation net returns decreased for all rotations with F-D-FP-D becoming the least profitable rotation. Increasing mustard prices increased all rotations that included mustard and improved the ranking of F-M-W-W (increased net returns 39%) ahead of the F-W-L-W rotation at base price levels.

Increasing pulse prices (field pea, chickpea and lentil) favoured rotations that included lentil due to lentil having the highest standard deviation of prices among the pulses. In general, increasing the pulse price by one standard deviation increased net returns by 23%-37% for rotations that included at least one pulse crop. The most profitable systems were F-CP-W-M, D-CP-M-W-L, and F-CP-W-W, ranking in the top three for all price scenarios. The least profitable system was F-D-FP-D when all prices were low. However, this system ranked as high as fourth when all prices were high.

In the Dark Brown soil zone, increasing the price of cereals (wheat and barley) increased the mean net return of all rotations and improved the ranking of F-W-L-W to number two from number three. Decreasing cereal prices resulted in negative returns for the F-B-W rotation but did not change the ranking of any of the nine rotations. Increasing oilseed prices (canola and flax) by one standard deviation increased the mean net return of the rotations with at least one oilseed from 24% to 45%, and increased the ranking of the C-W-FP rotation from six to two. Decreasing pulse prices (field pea and lentil) did not change the ranking of the rotations. C-W-L-W ranked first across all price scenarios. FX-B-L-W ranked second highest for all price scenarios except when all prices were low or when oilseed prices were low. In this later case, F-W-L-W moved up one ranking to number two and FX-B-L-W dropped one ranking to number three. The least profitable system was F-B-W in all price scenarios except when all cereal prices were high or when oilseed prices were low.

Financial Risk

In the case of agricultural production, risk is defined as the difference between what an individual producer perceives to be the consequence or outcome associated with a particular action and what actually occurs (Boehlje and Eidman, 1983). The effects of exogenous factors such as weather, disease, and insects combined with unknown input and output prices, makes farm management decisions inherently risky. As a result, output variables, such as crop yields, net incomes, and equity positions cannot be determined with certainty. These imperfect conditions present producers with the problem of having to make production decisions based on a number of competing alternatives, without prior knowledge of the final outcome of their selection. Therefore, the success of the farming enterprise is dependent on the ability of the farm manager to select strategies that provide the greatest probability of maximizing the goals of the farm.

When producers choose among cropping systems they must consider the trade-off between increased annual net returns and increased income variability or financial risk. Risk averse producers tend to choose cropping systems that display lower income variability. Therefore their final choice or selection of a cropping system depends on the risk attitudes of the individual, their expectations of product prices and input costs, and the nature of distributions of probable net returns that can be earned with each cropping system. The results of the stochastic dominance analysis for each of the rotations for both the Brown and Dark Brown soil zones are shown in Tables 12 and 13, respectively.

At the base price levels, producers in the Brown soil zone (regardless of the level of risk aversion would prefer the F-CP-W-M-W rotation (Table 12). In the Dark Brown soil zone producers with low or high risk aversion would choose the C-W-L-W rotation (Table 13).

Table 9. Average annual net Revenue by crop type for the Brown soil zone.

Rotation	Crop	Mean	Maximum	Minimum	Standard Deviation
		----------$/ha----------			
F-W-W	Wheat on Fallow	130.96	347.94	-65.87	108.75
	Wheat on Wheat	83.72	302.62	-114.31	125.97
F-M-W-W	Mustard on Fallow	204.27	445.51	-142.26	188.58
	Wheat on Mustard	90.57	296.94	-100.22	119.65
	Wheat on Wheat	53.49	202.80	-120.35	115.96
F-W-L-W	Wheat on Fallow	135.77	259.50	-64.83	102.99
	Lentil on Wheat	237.29	546.67	-69.56	182.33
	Wheat on Lentil	46.96	191.87	-121.88	108.65
F-CP-W-W	Chickpea on Fallow	491.54	711.24	-30.51	250.30
	Wheat on Chickpea	82.70	294.79	-103.46	120.19
	Wheat on Wheat	55.62	199.75	-118.80	111.51
F-D-FP-D	Durum on Fallow	164.28	290.11	-38.25	102.56
	Field Pea on Durum	89.71	438.88	-138.98	180.01
	Durum on Field Pea	76.07	220.50	-116.56	112.47
F-M-W-L-W	Mustard on Fallow	206.89	641.20	-43.75	227.60
	Wheat on Mustard	38.02	137.85	-123.46	79.17
	Lentil on Wheat	224.84	368.15	34.37	88.01
	Wheat on Lentil	21.97	166.75	-146.74	93.86
F-M-W-CP-W	Mustard on Fallow	211.38	624.27	-35.55	220.78
	Wheat on Mustard	41.81	144.32	-117.41	78.98
	Chickpea on Wheat	243.69	480.84	-8.14	130.97
	Wheat on Chickpea	25.54	173.36	-139.92	93.44
F-CP-W-M-W	Chickpea on Fallow	539.05	1219.31	158.99	370.13
	Wheat on Chickpea	37.28	143.38	-92.69	78.00
	Mustard on Wheat	94.09	261.16	-118.93	104.98
	Wheat on Mustard	28.78	182.03	-139.47	95.55
D-CP-M-W-L	Durum on Lentil	112.52	255.39	-61.54	88.65
	Chickpea on Durum	220.54	980.43	-58.55	337.14
	Mustard on Chickpea	109.39	351.79	-144.63	165.18
	Wheat on Mustard	37.34	122.64	-70.26	50.95
	Lentil on Wheat	203.09	450.94	-136.99	175.26

Table 10. Average annual net revenue by crop type for the Dark Brown soil zone.

Rotation	Crop	Mean	Maximum	Minimum	Standard Deviation
				$/ha	
F-B-W	Barley on Fallow	39.51	243.26	-169.45	137.08
	Wheat on Barley	116.55	281.04	-128.55	114.17
C-W-FP	Canola on Field Pea	91.73	612.07	-237.17	238.02
	Wheat on Canola	118.09	290.54	-90.10	122.22
	Field Pea on Wheat	106.63	355.91	-127.92	142.01
F-C-B-W	Canola on Fallow	344.91	632.62	-23.56	227.32
	Barley on Canola	-29.55	246.47	-239.43	142.03
	Wheat on Barley	70.16	237.72	-86.56	114.32
F-W-L-W	Wheat on Fallow	243.40	376.34	36.49	112.80
	Lentil on Wheat	231.42	588.63	-138.01	210.48
	Wheat on Lentil	60.52	234.47	-92.05	110.02
FP-W-B	Field Pea on Barley	156.50	658.84	-119.37	206.65
	Wheat on Field Pea	123.12	293.22	-89.92	122.44
	Barley on Wheat	-41.37	177.46	-197.82	79.17
C-W-L-W	Canola on Wheat	178.74	485.46	-126.74	181.97
	Wheat on Canola	122.22	310.68	-89.68	131.85
	Lentil on Wheat	221.93	581.07	-168.82	213.77
	Wheat on Lentil	63.24	238.77	-90.06	110.10
C-W-B-FP	Canola on Field Pea	152.61	488.76	-90.10	121.65
	Wheat on Canola	123.03	312.70	-162.18	210.08
	Barley on Wheat	-70.06	238.96	-264.92	114.37
	Field Pea on Barley	81.59	297.98	-87.80	163.92
C-B-FP-W	Canola on Wheat	147.03	498.50	-166.57	194.51
	Barley on Canola	-33.25	174.07	-225.74	138.86
	Field Pea on Barley	113.84	505.04	-157.53	188.22
	Wheat on Field Pea	69.47	242.72	-87.38	109.75
FX-B-L-W	Flax on Wheat	131.28	360.49	-96.66	124.38
	Barley on Flax	-36.64	166.07	-226.21	137.36
	Lentil on Barley	226.14	582.93	-139.33	210.99
	Wheat on Lentil	63.35	239.96	-90.69	110.44

Table 11 Annual Net returns for price scenarios in the Brown and Dark Brown soil zones.

Brown Soil Zone

Rotation	Base Prices	High prices for all crops	High prices for cereal crops	High prices of Oilseed Crops	High price for Pulse crops
F-W-W	54	95	95	54	54
F-M-W-W	65	130	91	105	65
F-W-L-W	82	131	112	82	101
F-CP-W-W	119	164	144	119	139
F-D-FP-D	60	126	112	60	74
F-M-W-L-W	80	144	100	109	95
F-M-W-CP-W	81	143	101	112	93
F-CP-W-M-W	124	182	143	146	141
D-CP-M-W-L	107	205	153	129	157
Rotation	Base Prices	Low prices for all crops	Low prices for cereal crops	Low prices of Oilseed Crops	Low price for Pulse crops
F-W-W	54	13	13	54	54
F-M-W-W	65	0	40	23	65
F-W-L-W	82	33	53	82	63
F-CP-W-W	119	74	94	119	99
F-D-FP-D	60	-7	7	60	45
F-M-W-L-W	80	15	60	49	64
F-M-W-CP-W	81	20	62	49	70
F-CP-W-M-W	124	65	105	101	106
D-CP-M-W-L	107	49	81	85	97

Dark Brown Soil Zone

Rotation	Base Prices	High prices for all crops	High prices for cereal crops	High prices of Oilseed Crops	High price for Pulse crops
F-B-W	34	90	90	34	34
C-W-FP	67	136	87	94	89
F-C-B-W	58	124	91	92	58
F-W-L-W	91	146	125	91	112
FP-W-B	57	122	100	57	80
C-W-L-W	122	200	151	151	143
C-W-B-FP	55	125	91	74	70
C-B-FP-W	60	136	95	87	60
FX-B-L-W	105	184	138	129	125
Rotation	Base Prices	Low prices for all crops	Low prices for cereal crops	Low prices of Oilseed Crops	Low price for Pulse crops
F-B-W	34	-22	-22	34	34
C-W-FP	67	-1	47	40	46
F-C-B-W	58	-8	26	25	58
F-W-L-W	91	35	56	91	70
FP-W-B	57	-7	15	57	35
C-W-L-W	122	44	93	93	101
C-W-B-FP	55	-15	19	36	40
C-B-FP-W	60	-15	26	33	46
FX-B-L-W	105	25	71	80	84

In general, producers in the Brown soil zone with medium to high aversion to risk would prefer rotations that include at least one pulse crop and one cereal crop. Mustard would be included in the rotation of a medium to high-risk averse producer only when cereal prices are low or oilseed prices are high. Three of the nine rotations would never be chosen regardless of risk preference: F-W-W, F-M-W-W and F-M-W-CP-W.

In the Dark Brown soil zone, the C-W-L-W rotation would be preferred by medium to high risk averse producers for all price scenarios except when oilseed or all crop prices are low, or when cereal prices are high. Under low cereal prices, risk averse producers would prefer the C-W-FP rotation. When all crop prices are high or cereal prices are high, or when oilseed prices are low, producers with low risk aversion would prefer the FP-W-B rotation.

Table 12. Risk efficient rotations at various grain prices for the Brown soil zone

	Level of risk aversion[a]		
Grain price scenarios	Low	Medium	High
Base prices	F-CP-W-M-W	F-CP-W-M-W	F-CP-W-M-W
High prices for all crops	F-W-L-W F-M-W-L-W D-CP-M-W-L	F-W-L-W	F-W-L-W
Low prices for all crops	F-CP-W-W	F-CP-W-W	F-CP-W-W
High cereal prices	F-D-FP-D D-CP-M-W-L	F-D-FP-D	F-D-FP-D
Low cereal prices	F-CP-W-M-W	F-CP-W-M-W	F-CP-W-M-W
High oilseed prices	D-CP-M-W-L	D-CP-M-W-L	D-CP-M-W-L
Low oilseed prices	F-CP-W-W F-D-FP-D D-CP-M-W-L	F-D-FP-D	F-D-FP-D
High pulse prices	F-CP-W-W	F-CP-W-W	F-CP-W-W
Low pulse prices	F-CP-W-W F-D-FP-D F-CP-W-M-W D-CP-M-W-L	F-CP-W-M-W	F-CP-W-M-W

[a]The Pratt-Arrow coefficients of absolute risk aversion were defined as low = 0 - .0075, medium = .0075 - .0225, and high = .0225 - .05. The low, medium and high designations are becoming less willing to gamble or accept risk.

Table 13. Risk efficient rotations at various grain prices for the Dark Brown soil zone

	Level of risk aversion[a]		
Grain price scenarios	Low	Medium	High
Base prices	C-W-L-W	C-W-L-W	C-W-L-W
High prices for all crops	C-W-L-W	C-W-L-W	C-W-L-W
Low prices for all crops	FP-W-B C-W-L-W	FP-W-B	FP-W-B
High cereal prices	FP-W-B C-W-L-W	FP-W-B	FP-W-B
Low cereal prices	C-W-L-W	C-W-FP C-W-L-W	C-W-FP
High oilseed prices	C-W-L-W	C-W-L-W	C-W-L-W
Low oilseed prices	FP-W-B C-W-L-W	FP-W-B	FP-W-B
High pulse prices	C-W-L-W	C-W-L-W	C-W-L-W
Low pulse prices	C-W-L-W	C-W-L-W	C-W-L-W

[a]The Pratt-Arrow coefficients of absolute risk aversion were defined as low = 0 - .0075, medium = .0075 - .0225, and high = .0225 - .05. The low, medium and high designations are becoming less willing to gamble or accept risk.

Soil Quality

Simulated SOC stocks increased for all rotations in both the Brown and Dark Brown soil zones (Figures 1 and 2). These rates of increase are comparable to previously reported rates for zero tillage management (Bruce et al. 1999). In the Brown soil zone SOC stocks increased by 0.52-0.77 t/ha/yr, with the largest increases attributed to the longer rotations. In the Dark Brown soil zone, SOC stocks increased by 0.84-1.08 t/ha/yr. Similar to the Brown soil zone, the more diversified rotations recorded the largest increases in SOC. It should be noted that the model includes no feedback between SOC stock equilibrium and accumulation rates. Therefore, in the real system increases in SOC of this magnitude would not continue for the entire 60 year period with increments decreasing as the equilibrium is approached.

Figure 1. SOC over the 60-year simulation period for the Brown soil zone

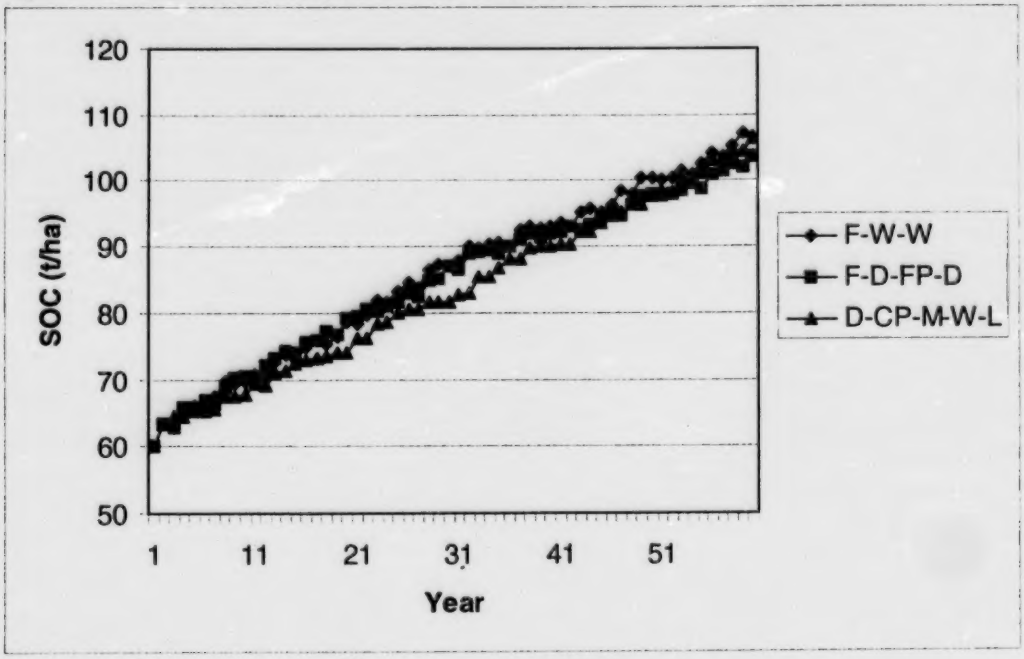
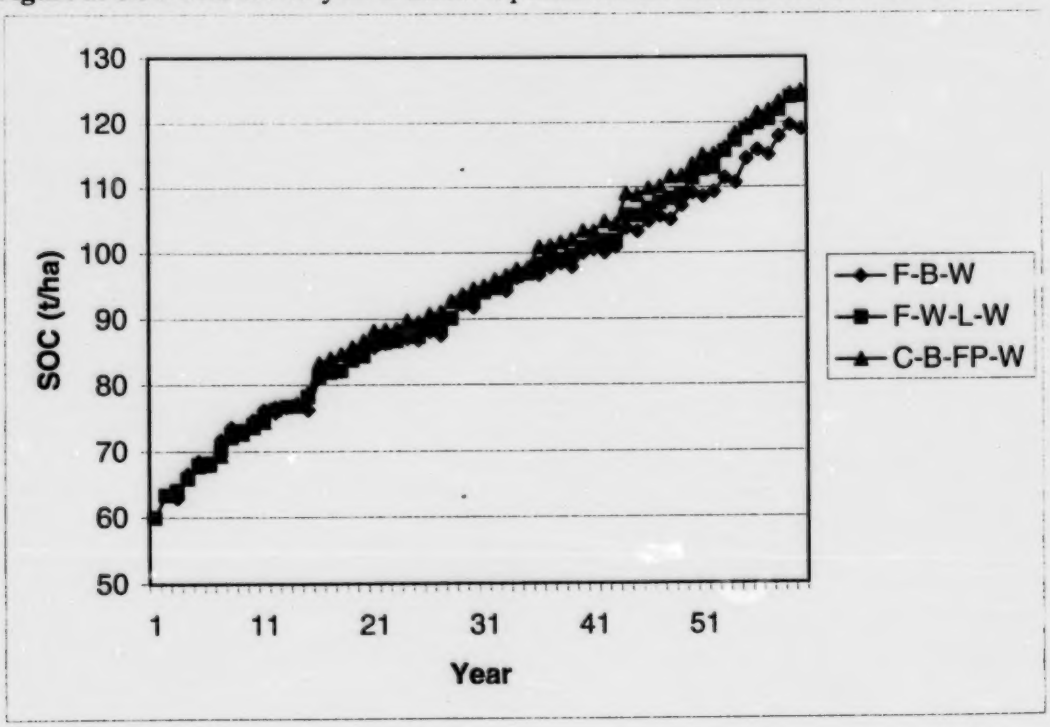


Figure 2. SOC over the 60-year simulation period for the Dark Brown soil zone



Conclusions

The objective of this study was to investigate the agronomic and economic merits of mixed cropping alternatives (pulses and oilseeds) to monoculture cereal systems, for the Brown and Dark Brown soil zones, and to determine if these diversified cropping systems enhance the overall economic and environmental sustainability of annual cropping systems in these regions. Under current market conditions, risk averse producers in the Brown soil zone would generally choose the 5-year F-CP-W-M-W rotation. In the Dark Brown soil zone risk averse producers would choose the 4-year C-W-L-W rotation.

In this investigation, the addition of pulse and oilseed crops to cereal-based rotations contributed positively to the profitability of farm enterprises in both soil zones. By extending crop rotations, producers are able to diversify their income source, create new marketing opportunities, capture rotational benefits, raise productivity, and spread out the workload in peak periods. Extended rotations also enhance cash flow as a result of being able to vary harvest dates, avoid restrictive quotas, and enter into planned delivery contracts throughout the year. Rotational benefits provide additional income enhancement opportunities through managing protein levels, reducing nitrogen requirements for crops following pulses, using the limited water more efficiently and benefiting from the micro-environment effects created by the various crop stubble types.

The negative implications of increasing cropping diversity are increased reliance on herbicides and pesticides, greater demand on management skills, and higher production risk. The increase in springtime cash outlay can be minimized with production contracts. However, this method of marketing tends to be restrictive and inflexible when commodity prices take favourable upward swings. Another pitfall to consider with non-cereal crops is the lack of efficient secondary markets for downgraded commodities. This may make the liquidation of lower quality grain samples more difficult.

Extending cereal-fallow based rotations with oilseed and pulse crops and reducing fallow frequency, contributes to higher net farm incomes, in both the Brown and Dark Brown soil zones, despite higher production costs. In this investigation the superior economic performance of the extended rotations can be attributed to the production of higher-valued crops and the accompanying rotational benefits, such as greater residual soil nutrients and moisture reserves and reduced soil losses. Although grain quality issues were not addressed specifically in this study, other studies suggest that these rotational benefits enhance the grain quality of subsequent cereal crops and lower their unit costs of production (Miller et al. 1997), further improving the profitability of diversified cropping systems.

References

Acton, D.F., G.A. Padbury and C.T. Stushnoff. 1998. The Ecoregions of Saskatchewan. Saskatchewan Environment and Resource Management. Canadian Plains Research Centre, Regina, Saskatchewan.

Acton, D.F. and L.J. Gregorich. 1995. The Health of Our Soils: Toward Sustainable Agriculture in Canada. Agriculture and Agri-Food, Canada.

Boehlje, M.D. and V.R. Eidman. Farm Management. John Wiley and Sons, Toronto. 1983.

Boehm, M.M. and D.W. Anderson. 1997. A Landscape-Scale Study of Soil Quality in Three Prairie Farming Systems. Soil Science Society of America Journal. 61:1147-1159.

Bruce, J.P., M. Frome, E. Haites, H. Janzen, R. Lal and K. Paustian. 1999. Carbon Sequestration in Soils. Journal of Soil and Water Conservation. 52:382-389.

de Jong, E. 1967. Moisture Retention of Selected Saskatchewan Soils. Soil Plant Nutrition. Saskatchewan Institute of Pedology No. M6, University of Saskatchewan, Saskatoon, Canada, pp. 51-73.

Douglas, D.L and R. W. Rickman. 1992. Estimating crop residue decomposition from air temperature, initial nitrogen content and residue placement. Soil Science Society of America Journal. 56:272-278.

Goh, S., Shih, C.C., Cochran, M.J., Raskin, R., 1989. A generalized stochastic dominance program for the IBM PC. Southern J. Agric. Econ. 21(2), 175-182.

Greer, K.J. and J.J. Schoenau. 1992. Characterizing Soil Phosphorus Supply on Aggrading and Degrading Management Regimes. Proceedings of the Soil and Crop Workshop, University of Saskatchewan, Saskatoon, Sask.

Hayenga, M.L., T, Mantsch. 1971. A generalized Systems Analysis Approach to Agricultural Sector Analysis, Michigan State University 1971.

Miller, P.R., D. Derksen and J, Waddington. 1997. Alternative Crops for Extending Spring Wheat Rotations in the semi-dry prairie. P. 520-523. In Soils and Crops '97. Proc. Workshop, Saskatoon, SK, Canada. 20-21 Feb. 1997 Ext. Div., University of Saskatchewan, Saskatoon, Sask. Canadá.

Moulin, A.P. and R. Beimuts. 1996. Residue Tillage Decision Support System (RTDS): Version 1.1. Melfort Research Station Technical Report.

Saliba, B.C An Economic Analysis of the Relationship between Soil Conservation and Farmland Characteristics. Unpublished Ph.D. Dissertation. Madison: University of Wisconsin, 1983.

Saskatchewan Agriculture and Food, 2001a. Farm Facts: Crop Planning Guide 2002 – Black Soil Zone.

Saskatchewan Agriculture and Food, 2001b. Farm Facts: Crop Planning Guide 2002 – Brown Soil Zone.

Saskatchewan Agriculture and Food, 2001c. Farm Facts: Crop Planning Guide 2002 Specialty Crops pulses, oilseeds, spices, and other crops.

Saskatchewan Agriculture and Food, 2001d. Agricultural Statistics 2000.

Weisensel, W.P. 1988. "The Economics of Soil Erosion in Saskatchewan" M.Sc. Thesis, University of Saskatchewan, Saskatoon, Saskatchewan. 1988.

Wischmeier, W.H. and D.D. Smith. 1978. Predicting Rainfall Erosion Losses. agricultural Handbook 537. U.S. Department of Agriculture. Agricultural Research Service. Washington, D.C.

Wall, D. D. 2000. "The Economics of Alternative Crops in the Brown and Dark Brown Soil zones of Saskatchewan". M.Sc. Thesis, University of Saskatchewan. 2000.

Wild, A. 1988. Russell's Soil Conditions and Plant Growth, 11th edition. Longman. Essex, UK. p.59.

Zentner, R.P., F.B. Dyck, K.R. Handford, C.A. Campbell, and F. Selles. 1993. "Economics of Flex-cropping in Southwestern Saskatchewan". Can. J. Plant Sci. July 1993.

Zentner, R.P., Selles, F., Campbell, C.A., Handford, K. and McConkey, B.G. 1992. Economics of fertilizer-N management for zero-till continuous spring wheat in the Brown soil zone. Can. J. Plant Sci. 72: 981-995.

Zentner, R.P, D. Wall, C. Nagy, E. Smith, D. Young, P. Miller, C. Campbell, B. McConkey, S. Brandt, G. Lafond, A. Johnston and D. Derksen. 2002. Economics of Crop Diversification ans soil Tillage Opportunities in the Canadian Prairies. Agron J. 94:216-230.

APPENDIX A: THE MODEL

The simulation model, constructed using the STELLA® Research modelling software, is comprised of environmental and economic sub-models. The environmental component simulates crop yields and soil quality dynamics based on the ability of soil to provide nitrogen (N), phosphorus (P) and water for crop growth. The economic component calculates rotation scale costs and revenues based on yield and input requirement data provided by the environmental sub-model. The simulations function at a one-year time step for a 60-year time horizon.

Environmental Model

The level of spatial aggregation in the model is the ecodistrtict, a unit of the Canadian Ecological Land Classification System defined by relatively homogeneous land form, vegetation and soil conditions (Acton et al. 1998). In order to simulate specific ecodistricts the model is parameterized using three categories of biophysical data: (1) soil type – soil texture, soil thickness; (2) weather conditions – growing season precipitation, over-winter precipitation, growing degree days, mean daily temperature; and (3) initial soil stocks – soil surface residue, soil N, soil P and SOC content.

Crop production potential for each ecodistrict is determined by the ability of the soil to provide nutrients and water for crop growth over time, hereafter referred to as soil quality. Soil quality is an endogenous variable determined by the biophysical characteristics including soil texture, cropping practices, crop types and tillage practices.

Crop production simulation is based on Liebig's concept of the Law of the Minimum (Wild 1988), such that maximum potential yield (Ymax in Table 1A) is achieved if all plant growth requirements are optimal, and crop yield declines in proportion to the most limiting growth requirement. To simulate prairie crop production conditions, the major crop requirements were assumed to be N, P and available soil

water. Mathematically, the model calculates a yield value for each crop (i) in context of the rotation (j) sequence (t) as follows:

$$Y_{ij}^{t} = Y\max_{i} \cdot Yns_{ij}^{t} \cdot Yps_{ij}^{t} \cdot Yws_{ij}^{t} \quad (1)$$

where, Y_{ij}^{t} represents yield for crop i in rotation j at time t (kg/ha), $Y\max_{i}$ is the maximum potential (unconstrained) yield (kg/ha), and Yns_{ij}^{t}, Yps_{ij}^{t}, Yws_{ij}^{t} are the indices for N, P and water sufficiency, respectively. The input sufficiencies in this relationship represent the proportion of maximum yield ($Y\max_{i}$) possible for each crop given the quantity of N, P and water available to the crop (Table A.1). These sufficiency values fall between zero and one, with a value of one reflecting optimal or non-constraining conditions. The sufficiency variables in this yield equation were parameterized using empirically derived relationships between historical yields for the specific crop type and N, P and water availability. The data for establishment of the relationships were obtained from the literature and personal communication with researchers. The environmental model simulates the amount of N, P and water available to the crop at each time step under each crop rotation, and from this information determines the sufficiency conditions.

An important driver in the environmental model is the stock of soil organic carbon (SOC). In general, soils with larger SOC stocks have greater water holding capacity and greater supplies of organic soil N and P (Boehm and Anderson 1997; Acton and Gregorich 1995). The stock of SOC at a point in time reflects the initial stock and the subsequent difference between the rate of addition of crop residue to the soil and the rate of organic matter loss as carbon dioxide (CO_2) due to microbial decomposition and respiration:

$$SOC_{ij}^{t} = R_{ij}^{t} - D_{ij}^{t} \quad (2)$$

where, R_{ij}^{t} represents the crop residue added to the soil (kg/ha/yr), and D_{ij}^{t} is the rate of residue decomposition (kg/ha/yr).

The quantity of crop residue added to the soil is a function of the crop type and crop yield:

$$R_{ij}^{t} = Y_{ij}^{t} \cdot C_i \cdot HI_i \quad (3)$$

where, C_i reflects the carbon content of the added biomass (assumed to be 45% on a dry weight basis), and HI_i is the harvest index (ratio of grain to total biomass production; Table A.1) (Moulin and Beimuts 1996).

The rate of residue decomposition is a function of the N content of the residue, soil moisture, tillage practice and solar energy input (Douglas and Rickman 1992):

$$D_{ij}^{t} = R_{ij}^{t} \cdot EXPf(N_i, G_j, k, GDD) \quad (4)$$

where, N_i is the nitrogen content of the residue (Table A.1), G_j represents a tillage factor, k is a constant (-0.0004; Douglas and Rickman 1992), and cumulative GDD is growing degree days above 5° C. The tillage factor (G_j) reflects the fact that greater tillage frequency increases the rate of decomposition by increasing soil disturbance, temperature, aeration and available N (Hendrix et al. 1988). Based on Douglas and Rickman (1992), the tillage factor for the modelled management methods were 0.3 for chemical fallow and 0.1 for zero tillage-management.

The SOC content and rate of N mineralization are the basis on which soil N content is calculated. SOC is assumed to have a C to N ratio of 10:1 (Parton et al. 1983; McGill et al. 1981) and the N is released to the soil at the rate of N mineralization, which varies as a function of soil thickness, soil temperature and soil moisture.

$$SoilN = N_{min} \cdot \left(\frac{SOC}{10} \right) \quad (5)$$

where, *SoilN* reflects the quantity of available N (kg/ha), N_{min} is the rate of N mineralization of SOC (kg/ha), and *SOC* is the stock of SOC (kg/ha). Processes that decrease soil thickness, such as erosion, result in decreased soil N due to losses of SOC and decreased mineralization rate, whereas production practices that increase soil temperature, soil moisture, SOC stock, or crop residue N content (e.g., legume production) increase the rate of N release. The production of N fixing crops also contributes directly to soil N content. It is assumed that biologically fixed N is added at the rate of 20 kg/ha/yr for field pea and lentil.

The quantity of N available to the crop at any time is the sum of soil N plus fertilizer N. Fertilizer N is assumed to be available only in the year of application. The quantity of N fertilizer added is constrained in the model such that total N does not exceed 100% sufficiency for each crop (e.g., it is assumed that producers base fertilization rates on soil test information) (Table A.1). N fertilizer rates are further adjusted based on available soil water at the beginning of the growing season. For example, the quantity of N fertilizer is scaled back from optimum rates if spring soil water conditions were less than 50 % of normal (Figure A.1). This relationship is based on the assumption that poor soil water conditions will cause producers to be less willing to invest in fertilizer inputs.

The quantity of available P is determined by the rate of P release from mineral, organic and fertilizer sources, minus the quantity exported with grain produced in the previous year (Table A.1). Mathematically, available soil P is calculated as:

$$Pa_j^t = \left(Po^t + Pi^t + \left(Pf_{ij}^t \cdot 0.25 \right) \right) \cdot Pu_i \quad (6)$$

where, Pa_j^t represents the quantity of available P (kg/ha/yr), Po^t is the mineralization rate of organic P (kg/ha/yr), Pi^t is the mineralization rate of inorganic P (kg/ha/yr), Pf_{ij}^t is the quantity of actual P fertilizer provided by the producer (kg/ha/yr) and Pu_i is the rate of P uptake by the crop (kg/ha/yr).

Organic P is a function of the SOC content, assuming a C:N:P ratio of 100:10:1, and a rate of organic P mineralization (Po^t) equal to the N mineralization rate. The total inorganic P content is based on soil texture, and is assumed to range between 2000 kg/ha for clay-textured soils and 80 kg/ha for sand-textured soils (Anderson, 1988), of which 0.4% is released on an annual basis, less the amount lost due to soil erosion. The quantity of P fertilizer added each year is constrained using the same procedures as for N fertilizer (Table A.1; Figure A.1), and it is assumed that 25% of the P fertilizer is available for plant growth in the year of application (Greer and Schoenau 1992).

Total soil water is based on the sum of precipitation received during the growing season (May to July) and snow-melt equivalent precipitation (non-growing season precipitation – August to April). Precipitation is a stochastic variable in the model with yearly growing season and non-growing season quantities being randomly selected from gamma distributions that were created based on long-term data from the specific study areas. The proportion of total precipitation that is available to the crop in each time step is determined by the infiltration rate, recharge rate, and water storage capacity of the soil. The rates of water infiltration and recharge, and the storage capacity of the soil are determined by soil texture, SOC, and soil erosion. The infiltration rate is calculated using the K (runoff) factor from the Universal Soil Loss Equation (Wischmeier and Smith, 1978), such that 1-K is the proportion of water that enters the soil. The recharge rate for precipitation received in non-growing season months enters the soil as run-off at one half

the infiltration rate, based on the assumption that over-winter recharge of stubble is equivalent to about half of the snow water received during the winter.

The available water storage capacity of the soil (AWSC) determines the water available for crop growth and is assumed to be the amount of water that can be held in the soil between field capacity (FC) and wilting point (WP) as determined by de Jong (1967) for Canadian prairie soils. The AWSC is a function of soil texture and SOC content:

$$AWSC = ((BD \cdot \frac{solum}{100}) \cdot FC - WP \tag{7}$$

where, BD is the bulk density (kg/m^3) and solum is soil thickness (cm). The FC and WP water contents (de Jong, 1967) are:

$$\begin{aligned} FC &= 0.99 + (0.5595\%clay) + (1.4OM) \\ WP &= 0.753 + (0.334\%clay) + (1.03OM) \end{aligned} \tag{8}$$

where, *%clay* is soil clay content and *OM* is soil organic matter content. It is assumed that 30% of the water stored during a summerfallow year is available to the subsequent crop.

Economic Model

The economic model calculates profit for the specific rotations in each year of the 60-year time period based on crop yield, simulated by the environmental sub-model, and production cost data. The rotation scale profits are calculated as a rolling sum of profits for all crops in the rotation:

$$\Pi'_j = \sum_{i=1}^{n} \left(\mathrm{Pr}_i Y'_{ij} - w_{ij} - s_i Y'_{ij} - rNf'_{ij} - gPf'_{ij} \right) \tag{9}$$

where, Π'_j are the profits for rotation j at time t (\$/ha), n is the number of crops (i) in rotation j, Pr_i is the constant output price for crop i (\$/t), w_{ij} is a vector of fixed production costs for crop i in rotation j (\$/ha), s_i reflects transportation costs for crop i (\$/t), r and g are fixed fertilizer costs for N and P respectively (\$/kg), and Nf'_{ij} and Pf'_{ij}

are the N and P fertilizer application rates, respectively, for crop *i* in rotation *j* at time *t* (kg/ha). Production costs that are held constant for each simulation under each management method and crop type include pesticides, seed, fuel, labour, land and overhead costs. It should be noted that although harvesting costs (eg. combining and transport to on-farm storage), including fuel, repairs and labour, are yield dependent, the model assumed these costs were constant. Fertilizer, and transportation costs from farm to delivery point are calculated based on application rates and crop yield, respectively, as determined by the environmental model. This framework ensures that feedback between the environmental and economic components is captured, and as a result, changes in soil quality influence rotation profitability.

The economic model does not include a mechanism for optimization, and in this way differs from most of the past research that has focused on the economic value of soil quality attributes. However, the absolute and relative profitability of the modelled crop rotations, as influenced by changes in soil quality and within the context of specific biophysical and economic conditions, are provided by the model. A comparison of the long-term economic characteristics of the rotations is facilitated by evaluating the discounted stream of profits. This information is used to calculate the economic value of soil quality changes in the crop rotation context. Marginal user cost (MUC) is the present value of the change in net returns due to changes in soil quality (McConnell 1983) and is often interpreted as an economic cost of soil degradation or erosion. The marginal user benefit (MUB) is a concept similar to MUC except that it is specifically interpreted as a benefit. The MUB is the present value of the increase in net revenue that is attributable to an increase in soil quality (Smith et al. 2000a). The modelling framework also facilitates calculation of the opportunity cost of each rotation, relative to a benchmark or traditional

rotation in each soil climatic zone. In addition, since precipitation is stochastic the simulation output can provide insight into the relative economic risk associated with each cropping system. Further, the relationship between changes in soil quality and economic risk can be evaluated using this framework.

Table A.1. Values used to parameterize the environmental model.

Crop	Ymax (t/ha)[a]	Harvest Index (kg residue/kg grain)[b]	N content of residue (g/kg)[c]	100% N sufficiency (kg/ha)[d]	P export (kg/t of (grain)[e]	100% P sufficiency (kg/ha)[f]
Spring Wheat	3.80	2.20	2.07	95	4.10	40
Durum	3.80	2.20	2.07	95	4.10	40
Mustard	3.00	2.20	1.43	115	10.00	44
Barley	6.00	2.20	2.07	100	3.60	31
Canola	3.10	2.20	1.43	115	10.00	44
Flax	3.40	1.80	1.43	115	4.80	42
Peas	5.00	1.20	2.36	40	5.00	20
Lentils	2.50	1.20	2.36	20	5.20	20
Chickpea	3.00	1.20	2.20	30	5.00	30

[a] Source: author's calculations based on range of sources.
[b] Source: Moulin and Beimuts (1996).
[c] Source: Douglas and Rickman (1992).
[d] Source: Roberts and Green (1994).

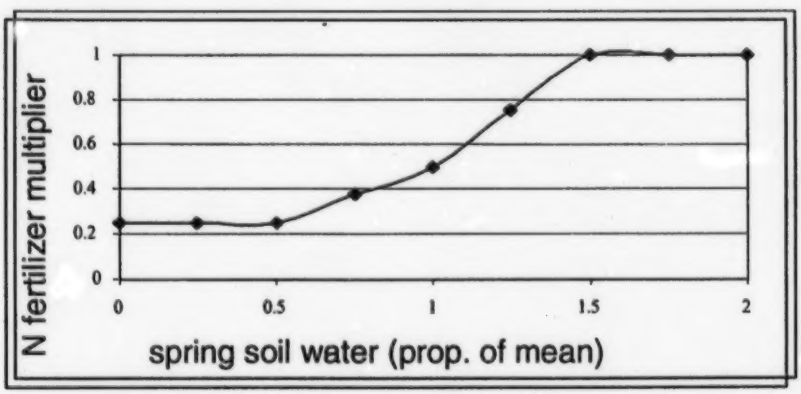


Figure A.1. N and P fertilizer multiplier as a function of the proportion of spring soil water relative to average soil water in the region.

APPENDIX B: Production Costs for Rotations

F-W-W Rotation **Brown Soil Zone ($/ha)**

Cost Item	Fallow	Wheat	Wheat	Rotation
Seed	0.00	16.33	16.33	10.89
Fertilizer N	0.00	30.00	30.58	20.19
Fertilizer P	0.00	13.64	13.90	9.18
Fertilizer S	0.00	0.00	0.00	0.00
Pesticides	29.38	33.61	41.98	34.99
Fuel	2.07	17.64	14.52	11.41
Machine Repair	3.71	14.83	12.36	10.30
Custom Work & Hired Labor	0.00	12.36	12.36	8.24
Crop Insurance	0.00	5.58	4.03	3.20
Utilities& Miscel	7.17	7.17	7.17	7.17
Interest	3.34	3.46	3.93	3.58
Transport (Farm to Elevator)	0.00	16.81	14.55	10.45
Total Variable	**45.67**	**171.43**	**171.71**	**129.60**
Building Repair	2.22	2.22	2.22	2.22
Property Taxes	10.30	10.30	10.30	10.30
Insurance & Licenses	2.92	2.92	2.92	2.92
Machine & Building Dep. & Inv.	15.89	49.79	42.25	35.98
Total Other Costs	**31.33**	**65.23**	**57.69**	**51.42**
Total Cost	**77.00**	**236.66**	**229.40**	**181.02**

F-M-W-W Rotation **Brown Soil Zone ($/ha)**

Cost Item	Fallow	Mustard	Wheat	Wheat	Rotation
Seed	0.00	10.87	16.33	16.33	10.88
Fertilizer N	0.00	33.57	31.72	29.63	23.73
Fertilizer P	0.00	14.60	14.41	13.34	10.59
Fertilizer S	0.00	5.68	0.00	0.00	1.42
Pesticides	29.38	58.51	41.98	41.98	42.96
Fuel	2.07	18.68	14.52	14.52	12.45
Machine Repair	3.71	14.83	12.36	12.36	10.82
Custom Work & Hired Labor	0.00	8.65	12.36	12.36	8.34
Crop Insurance	0.00	6.99	4.03	4.03	3.76
Utilities& Miscel	7.17	7.17	7.17	7.17	7.17
Interest	3.34	4.10	3.93	3.93	3.83
Transport (Farm to Elevator)	0.00	11.32	14.95	13.00	9.82
Total Variable	**45.67**	**194.97**	**173.76**	**168.65**	**145.76**
Building Repair	2.22	2.22	2.22	2.22	2.22
Property Taxes	10.30	10.30	10.30	10.30	10.30
Insurance & Licenses	2.92	2.92	2.92	2.92	2.92
Machine & Building Dep. & Inv.	15.89	49.79	42.25	42.25	37.55
Total Other Costs	**31.33**	**65.23**	**57.69**	**57.69**	**52.99**
Total Cost	**77.00**	**260.20**	**231.45**	**226.34**	**198.75**

F-W-L-W Rotation **Brown Soil Zone ($/ha)**

Cost Item	Fallow	Wheat	Lentil	Wheat	Rotation
Seed	0.00	16.33	46.70	16.33	19.84
Fertilizer N	0.00	29.19	0.00	29.36	14.64
Fertilizer P	0.00	13.26	10.80	13.34	9.35
Fertilizer S	0.00	0.00	0.00	0.00	0.00
Pesticides	29.38	33.61	99.90	41.98	51.22
Fuel	2.07	17.64	16.61	14.52	12.71
Machine Repair	3.71	14.83	19.27	12.36	12.54
Custom Work & Hired Labor	0.00	12.36	7.41	12.36	8.03
Crop Insurance	0.00	5.58	12.40	4.03	5.50
Utilities& Miscel	7.17	7.17	7.17	7.17	7.17
Interest	3.34	3.46	5.98	3.93	4.18
Transport (Farm to Elevator)	0.00	17.00	11.36	12.68	10.26
Total Variable	**45.67**	**170.43**	**237.60**	**168.06**	**155.44**
Building Repair	2.22	2.22	2.22	2.22	2.22
Property Taxes	10.30	10.30	10.30	10.30	10.30
Insurance & Licenses	2.92	2.92	2.92	2.92	2.92
Machine & Building Dep. & Inv.	15.89	49.79	53.57	42.25	40.38
Total Other Costs	**31.33**	**65.23**	**69.01**	**57.69**	**55.82**
Total Cost	**77.00**	**235.66**	**306.61**	**225.75**	**211.26**

F-CP-W-W Rotation **Brown Soil Zone ($/ha)**

Cost Item	Fallow	Chickpea	Wheat	Wheat	Rotation
Seed	0.00	111.44	16.33	16.33	36.03
Fertilizer N	0.00	0.00	31.74	29.36	15.28
Fertilizer P	0.00	9.96	14.41	13.34	9.43
Fertilizer S	0.00	0.00	0.00	0.00	0.00
Pesticides	29.38	106.33	41.98	41.98	54.92
Fuel	2.07	22.83	14.52	14.52	13.49
Machine Repair	3.71	22.24	12.36	12.36	12.67
Custom Work & Hired Labor	0.00	7.41	12.36	12.36	8.03
Crop Insurance	0.00	28.84	4.03	4.03	9.23
Utilities& Miscel	7.17	7.17	7.17	7.17	7.17
Interest	3.34	8.52	3.93	3.93	4.93
Transport (Farm to Elevator)	0.00	11.21	14.56	13.10	9.72
Total Variable	**45.67**	**335.95**	**173.39**	**168.48**	**180.87**
Building Repair	2.22	2.22	2.22	2.22	2.22
Property Taxes	10.30	10.30	10.30	10.30	10.30
Insurance & Licenses	2.92	2.92	2.92	2.92	2.92
Machine & Building Dep. & Inv.	15.89	61.11	42.25	42.25	40.38
Total Other Costs	**31.33**	**76.55**	**57.69**	**57.69**	**55.82**
Total Cost	**77.00**	**412.50**	**231.08**	**226.17**	**236.69**

F-D-FP-D Rotation **Brown Soil Zone ($/ha)**

Cost Item	Fallow	Durum	Pea	Durum	Rotation
Seed	0.00	21.92	44.48	21.92	22.08
Fertilizer N	0.00	19.30	1.52	19.34	10.04
Fertilizer P	0.00	11.96	12.14	11.98	9.02
Fertilizer S	0.00	0.00	0.00	0.00	0.00
Pesticides	29.38	34.32	59.06	42.70	41.37
Fuel	2.07	17.64	22.83	14.52	14.27
Machine Repair	3.71	14.83	28.17	12.36	14.77
Custom Work & Hired Labor	0.00	12.36	7.41	12.36	8.03
Crop Insurance	0.00	5.34	5.58	3.76	3.67
Utilities& Miscel	7.17	7.17	7.17	7.17	7.17
Interest	3.34	3.63	5.16	4.08	4.05
Transport (Farm to Elevator)	0.00	17.76	18.55	13.55	12.47
Total Variable	**45.67**	**166.23**	**212.07**	**163.74**	**146.93**
Building Repair	2.22	2.22	2.22	2.22	2.22
Property Taxes	10.30	10.30	10.30	10.30	10.30
Insurance & Licenses	2.92	2.92	2.92	2.92	2.92
Machine & Building Dep. & Inv.	15.89	49.79	79.71	42.25	46.91
Total Other Costs	**31.33**	**65.23**	**95.15**	**57.69**	**62.35**
Total Cost	**77.00**	**231.46**	**307.22**	**221.43**	**209.28**

F-M-W-L-W Rotation **Brown Soil Zone ($/ha)**

Cost Item	Fallow	Mustard	Wheat	Lentil	Wheat	Rotation
Seed	0.00	10.87	16.33	46.70	16.33	18.05
Fertilizer N	0.00	37.18	29.26	0.00	28.99	19.09
Fertilizer P	0.00	9.44	16.61	4.15	16.54	9.35
Fertilizer S	0.00	5.68	0.00	0.00	0.00	1.14
Pesticides	29.38	58.51	41.98	99.90	41.98	54.35
Fuel	2.07	18.68	14.52	16.61	14.52	13.28
Machine Repair	3.71	14.83	12.36	19.27	12.36	12.51
Custom Work & Hired Labor	0.00	8.65	12.36	7.41	12.36	8.16
Crop Insurance	0.00	6.99	4.03	12.40	4.03	5.49
Utilities& Miscel	7.17	7.17	7.17	7.17	7.17	7.17
Interest	3.34	4.10	3.93	5.98	3.93	4.26
Transport (Farm to Elevator)	0.00	13.23	12.82	10.76	11.70	9.70
Total Variable	**45.67**	**195.33**	**171.37**	**230.35**	**169.91**	**162.53**
Building Repair	2.22	2.22	2.22	2.22	2.22	2.22
Property Taxes	10.30	10.30	10.30	10.30	10.30	10.30
Insurance & Licenses	2.92	2.92	2.92	2.92	2.92	2.92
Machine & Building Dep. & Inv.	15.89	49.79	42.25	53.57	42.25	40.75
Total Other Costs	**31.33**	**65.23**	**57.69**	**69.01**	**57.69**	**56.19**
Total Cost	**77.00**	**260.56**	**229.06**	**299.36**	**227.60**	**218.72**

F-M-W-CP-W Rotation **Brown Soil Zone ($/ha)**

Cost Item	Fallow	Mustard	Wheat	Chickpea	Wheat	Rotation
Seed	0.00	10.87	16.33	111.44	16.33	30.99
Fertilizer N	0.00	37.18	23.41	0.05	23.19	16.77
Fertilizer P	0.00	13.18	15.52	16.60	15.38	12.14
Fertilizer S	0.00	5.68	0.00	0.00	0.00	1.14
Pesticides	29.38	58.51	41.98	106.33	41.98	55.64
Fuel	2.07	18.68	14.52	22.83	14.52	14.52
Machine Repair	3.71	14.83	12.36	22.24	12.36	13.10
Custom Work & Hired Labor	0.00	8.65	12.36	7.41	12.36	8.16
Crop Insurance	0.00	6.99	4.03	28.84	4.03	8.78
Utilities& Miscel	7.17	7.17	7.17	7.17	7.17	7.17
Interest	3.34	4.10	3.93	8.52	3.93	4.76
Transport (Farm to Elevator)	0.00	13.91	12.30	9.19	11.19	9.32
Total Variable	**45.67**	**199.75**	**163.91**	**340.62**	**162.44**	**182.48**
Building Repair	2.22	2.22	2.22	2.22	2.22	2.22
Property Taxes	10.30	10.30	10.30	10.30	10.30	10.30
Insurance & Licenses	2.92	2.92	2.92	2.92	2.92	2.92
Machine & Building Dep. & Inv.	15.89	49.79	42.25	61.11	42.25	42.26
Total Other Costs	**31.33**	**65.23**	**57.69**	**76.55**	**57.69**	**57.70**
Total Cost	**77.00**	**264.98**	**221.60**	**417.17**	**220.13**	**240.18**

F-CP-W-M-W Rotation **Brown Soil Zone ($/ha)**

Cost Item	Fallow	Chickpea	Wheat	Mustard	Wheat	Rotation
Seed	0.00	111.44	16.33	10.87	16.33	30.99
Fertilizer N	0.00	0.12	23.41	34.04	23.19	16.15
Fertilizer P	0.00	12.88	15.52	17.28	15.38	12.21
Fertilizer S	0.00	0.00	0.00	5.68	0.00	1.14
Pesticides	29.38	106.33	41.98	60.29	41.98	55.99
Fuel	2.07	22.83	14.52	15.57	14.52	13.90
Machine Repair	3.71	22.24	12.36	12.36	12.36	12.61
Custom Work & Hired Labor	0.00	7.41	12.36	8.65	12.36	8.16
Crop Insurance	0.00	28.84	4.03	4.77	4.03	8.33
Utilities& Miscel	7.17	7.17	7.17	7.17	7.17	7.17
Interest	3.34	8.52	3.93	4.35	3.93	4.81
Transport (Farm to Elevator)	0.00	15.17	11.97	8.85	11.33	9.46
Total Variable	**45.67**	**342.95**	**163.58**	**189.88**	**162.58**	**180.93**
Building Repair	2.22	2.22	2.22	2.22	2.22	2.22
Property Taxes	10.30	10.30	10.30	10.30	10.30	10.30
Insurance & Licenses	2.92	2.92	2.92	2.92	2.92	2.92
Machine & Building Dep. & Inv.	15.89	61.11	42.25	42.25	42.25	40.75
Total Other Costs	**31.33**	**76.55**	**57.69**	**57.69**	**57.69**	**56.19**
Total Cost	**77.00**	**419.50**	**221.27**	**247.57**	**220.27**	**237.12**

D-CP-M-W-L Rotation **Brown Soil Zone ($/ha)**

Cost Item	Durum	Chickpea	Mustard	Wheat	Lentil	Rotation
Seed	21.92	111.44	10.87	16.33	46.70	41.45
Fertilizer N	35.03	0.04	33.64	23.64	0.00	18.47
Fertilizer P	19.01	12.88	17.08	15.70	15.38	16.01
Fertilizer S	0.00	0.00	5.68	0.00	0.00	1.14
Pesticides	42.70	106.33	60.29	41.98	99.90	70.24
Fuel	14.52	22.83	15.57	14.52	16.61	16.81
Machine Repair	12.36	22.24	12.36	12.36	19.27	15.72
Custom Work & Hired Labor	12.36	7.41	8.65	12.36	7.41	9.64
Crop Insurance	3.76	28.84	4.77	4.03	12.40	10.76
Utilities& Miscel	7.17	7.17	7.17	7.17	7.17	7.17
Interest	4.08	8.52	4.35	3.93	5.98	5.37
Transport (Farm to Elevator)	17.25	9.69	9.31	11.87	10.45	11.71
Total Variable	**190.16**	**337.39**	**189.74**	**163.89**	**241.27**	**224.49**
Building Repair	2.22	2.22	2.22	2.22	2.22	2.22
Property Taxes	10.30	10.30	10.30	10.30	10.30	10.30
Insurance & Licenses	2.92	2.92	2.92	2.92	2.92	2.92
Machine & Building Dep. & Inv.	42.25	61.11	42.25	42.25	53.57	48.29
Total Other Costs	**57.69**	**76.55**	**57.69**	**57.69**	**69.01**	**63.73**
Total Cost	**247.85**	**413.94**	**247.43**	**221.58**	**310.28**	**288.22**

F-B-W Rotation **Dark Brown Soil Zone ($/ha)**

Cost Item	Fallow	Barley	Wheat	Rotation
Seed	0.00	16.43	17.77	11.40
Fertilizer N	0.00	35.24	31.72	22.32
Fertilizer P	0.00	16.04	10.20	8.75
Fertilizer S	0.00	0.00	0.00	0.00
Pesticides	29.38	51.74	52.24	44.45
Fuel	2.08	14.53	14.53	10.38
Machine Repair	5.07	15.44	15.44	11.98
Custom Work & Hired Labor	0.00	10.50	12.97	7.82
Crop Insurance	0.00	5.51	4.30	3.27
Utilities& Miscel	10.60	10.60	10.60	10.60
Interest	3.76	4.55	4.62	4.31
Transport (Farm to Elevator)	0.00	18.97	17.33	12.10
Total Variable	**50.89**	**199.55**	**191.72**	**147.39**
Building Repair	2.97	2.97	2.97	2.97
Property Taxes	11.69	11.69	11.69	11.69
Insurance & Licenses	4.47	4.47	4.47	4.47
Machine & Building Dep. & Inv.	21.55	53.20	53.20	42.65
Total Other Costs	**40.68**	**72.33**	**72.33**	**61.78**
Total Cost	**91.57**	**271.88**	**264.05**	**209.17**

C-W-FP Rotation **Dark Brown Soil Zone ($/ha)**

Cost Item	Canola	Wheat	Pea	Rotation
Seed	29.65	17.77	44.48	30.63
Fertilizer N	37.30	33.48	0.00	23.59
Fertilizer P	16.70	16.04	12.10	14.95
Fertilizer S	8.52	0.00	0.00	2.84
Pesticides	71.26	52.24	64.17	62.56
Fuel	15.57	14.53	16.61	15.57
Machine Repair	15.44	15.44	22.98	17.95
Custom Work & Hired Labor	10.50	12.97	7.41	10.29
Crop Insurance	4.92	4.30	4.42	4.55
Utilities& Miscel	10.60	10.60	10.60	10.60
Interest	5.66	4.62	5.02	5.10
Transport (Farm to Elevator)	9.85	17.63	18.53	15.34
Total Variable	**235.97**	**199.62**	**206.32**	**213.97**
Building Repair	2.97	2.97	2.97	2.97
Property Taxes	11.69	11.69	11.69	11.69
Insurance & Licenses	4.47	4.47	4.47	4.47
Machine & Building Dep. & Inv.	53.20	53.20	64.52	56.97
Total Other Costs	**72.33**	**72.33**	**83.65**	**76.10**
Total Cost	**308.30**	**271.95**	**289.97**	**290.07**

FP-W-B Rotation **Dark Brown Soil Zone ($/ha)**

Cost Item	Pea	Wheat	Barley	Rotation
Seed	44.48	17.77	16.43	26.23
Fertilizer N	0.00	33.48	33.38	22.29
Fertilizer P	11.38	16.04	11.94	13.12
Fertilizer S	0.00	0.00	0.00	0.00
Pesticides	64.17	52.24	51.74	56.05
Fuel	16.61	14.53	14.53	15.22
Machine Repair	22.98	15.44	15.44	17.95
Custom Work & Hired Labor	7.41	12.97	10.50	10.29
Crop Insurance	4.42	4.30	5.51	4.74
Utilities& Miscel	10.60	10.60	10.60	10.60
Interest	5.02	4.62	4.55	4.73
Transport (Farm to Elevator)	20.99	17.88	16.58	18.48
Total Variable	**208.06**	**199.87**	**191.20**	**199.71**
Building Repair	2.97	2.97	2.97	2.97
Property Taxes	11.69	11.69	11.69	11.69
Insurance & Licenses	4.47	4.47	4.47	4.47
Machine & Building Dep. & Inv.	64.52	53.20	53.20	56.97
Total Other Costs	**83.65**	**72.33**	**72.33**	**76.10**
Total Cost	**291.71**	**272.20**	**263.53**	**275.81**

F-C-B-W Rotation **Dark Brown Soil Zone ($/ha)**

Cost Item	Fallow	Canola	Barley	Wheat	Rotation
Seed	0.00	29.65	16.43	17.77	15.96
Fertilizer N	0.00	42.05	33.41	30.09	26.39
Fertilizer P	0.00	18.58	8.28	15.82	10.67
Fertilizer S	0.00	8.52	0.00	0.00	2.13
Pesticides	29.38	61.45	51.74	52.24	48.70
Fuel	2.08	18.68	14.53	14.53	12.46
Machine Repair	5.07	17.91	15.44	15.44	13.47
Custom Work & Hired Labor	0.00	10.50	10.50	12.97	8.49
Crop Insurance	0.00	6.28	5.51	4.30	4.02
Utilities& Miscel	10.60	10.60	10.60	10.60	10.60
Interest	3.76	5.16	4.55	4.62	4.52
Transport (Farm to Elevator)	0.00	16.45	22.85	15.14	13.61
Total Variable	**50.89**	**245.83**	**193.84**	**193.52**	**171.02**
Building Repair	2.97	2.97	2.97	2.97	2.97
Property Taxes	11.69	11.69	11.69	11.69	11.69
Insurance & Licenses	4.47	4.47	4.47	4.47	4.47
Machine & Building Dep. & Inv.	21.55	60.74	53.20	53.20	47.17
Total Other Costs	**40.68**	**79.87**	**72.33**	**72.33**	**66.30**
Total Cost	**91.57**	**325.70**	**266.17**	**265.85**	**237.32**

F-W-L-W Rotation **Dark Brown Soil Zone ($/ha)**

Cost Item	Fallow	Wheat	Lentil	Wheat	Rotation
Seed	0.00	17.77	46.70	17.77	20.56
Fertilizer N	0.00	35.24	0.00	30.09	16.33
Fertilizer P	0.00	16.88	5.32	14.41	9.15
Fertilizer S	0.00	0.00	0.00	0.00	0.00
Pesticides	29.38	43.88	99.90	52.24	56.35
Fuel	2.08	17.64	16.61	14.53	12.72
Machine Repair	5.07	17.91	22.98	15.44	15.35
Custom Work & Hired Labor	0.00	12.97	7.41	12.97	8.34
Crop Insurance	0.00	5.11	14.01	4.30	5.86
Utilities& Miscel	10.60	10.60	10.60	10.60	10.60
Interest	3.76	4.15	6.28	4.62	4.70
Transport (Farm to Elevator)	0.00	23.81	12.43	14.64	12.72
Total Variable	**50.89**	**205.96**	**242.24**	**191.61**	**172.68**
Building Repair	2.97	2.97	2.97	2.97	2.97
Property Taxes	11.69	11.69	11.69	11.69	11.69
Insurance & Licenses	4.47	4.47	4.47	4.47	4.47
Machine & Building Dep. & Inv.	21.55	60.74	64.52	53.20	50.00
Total Other Costs	**40.68**	**79.87**	**83.65**	**72.33**	**69.13**
Total Cost	**91.57**	**285.83**	**325.89**	**263.94**	**241.81**

C-W-L-W Rotation **Dark Brown Soil Zone ($/ha)**

Cost Item	Canola	Wheat	Lentil	Wheat	Rotation
Seed	29.65	17.77	46.70	17.77	27.97
Fertilizer N	28.84	35.24	0.00	30.09	23.54
Fertilizer P	15.88	16.88	7.60	14.41	13.69
Fertilizer S	8.52	0.00	0.00	0.00	2.13
Pesticides	71.26	52.24	99.90	52.24	68.91
Fuel	15.57	14.53	16.61	14.53	15.31
Machine Repair	15.44	15.44	22.98	15.44	17.33
Custom Work & Hired Labor	10.50	12.97	7.41	12.97	10.96
Crop Insurance	4.92	4.30	14.01	4.30	6.88
Utilities& Miscel	10.60	10.60	10.60	10.60	10.60
Interest	5.66	4.62	6.28	4.62	5.30
Transport (Farm to Elevator)	12.09	17.94	12.25	14.78	14.27
Total Variable	**228.93**	**202.53**	**244.34**	**191.75**	**216.89**
Building Repair	2.97	2.97	2.97	2.97	2.97
Property Taxes	11.69	11.69	11.69	11.69	11.69
Insurance & Licenses	4.47	4.47	4.47	4.47	4.47
Machine & Building Dep. & Inv.	53.20	53.20	64.52	53.20	56.03
Total Other Costs	**72.33**	**72.33**	**83.65**	**72.33**	**75.16**
Total Cost	**301.26**	**274.86**	**327.99**	**264.08**	**292.05**

C-W-B-FP Rotation **Dark Brown Soil Zone ($/ha)**

Cost Item	Canola	Wheat	Barley	Pea	Rotation
Seed	29.65	17.77	16.43	44.48	27.08
Fertilizer N	31.85	35.24	31.74	0.00	24.71
Fertilizer P	13.06	16.88	11.78	8.60	12.58
Fertilizer S	8.52	0.00	0.00	0.00	2.13
Pesticides	71.26	52.24	51.74	64.17	59.85
Fuel	15.57	14.53	14.53	16.61	15.31
Machine Repair	15.44	15.44	15.44	22.98	17.33
Custom Work & Hired Labor	10.50	12.97	10.50	7.41	10.35
Crop Insurance	4.92	4.30	5.51	4.42	4.79
Utilities& Miscel	10.60	10.60	10.60	10.60	10.60
Interest	5.66	4.62	4.55	5.02	4.96
Transport (Farm to Elevator)	9.37	17.98	19.55	17.15	16.01
Total Variable	**226.40**	**202.57**	**192.37**	**201.44**	**205.70**
Building Repair	2.97	2.97	2.97	2.97	2.97
Property Taxes	11.69	11.69	11.69	11.69	11.69
Insurance & Licenses	4.47	4.47	4.47	4.47	4.47
Machine & Building Dep. & Inv.	53.20	53.20	53.20	64.52	56.03
Total Other Costs	**72.33**	**72.33**	**72.33**	**83.65**	**75.16**
Total Cost	**298.73**	**274.90**	**264.70**	**285.09**	**280.86**

C-B-FP-W Rotation **Dark Brown Soil Zone ($/ha)**

Cost Item	Canola	Barley	Pea	Wheat	Rotation
Seed	29.65	16.43	44.48	17.77	27.08
Fertilizer N	38.84	35.24	0.00	30.09	26.04
Fertilizer P	15.92	13.08	11.40	14.41	13.70
Fertilizer S	8.52	0.00	0.00	0.00	2.13
Pesticides	71.26	51.74	64.17	52.24	59.85
Fuel	15.57	14.53	16.61	14.53	15.31
Machine Repair	15.44	15.44	22.98	15.44	17.33
Custom Work & Hired Labor	10.50	10.50	7.41	12.97	10.35
Crop Insurance	4.92	5.51	4.42	4.30	4.79
Utilities& Miscel	10.60	10.60	10.60	10.60	10.60
Interest	5.66	4.55	5.02	4.62	4.96
Transport (Farm to Elevator)	11.30	22.90	18.87	15.08	17.04
Total Variable	**238.18**	**200.52**	**205.96**	**192.05**	**209.18**
Building Repair	2.97	2.97	2.97	2.97	2.97
Property Taxes	11.69	11.69	11.69	11.69	11.69
Insurance & Licenses	4.47	4.47	4.47	4.47	4.47
Machine & Building Dep. & Inv.	53.20	53.20	64.52	53.20	56.03
Total Other Costs	**72.33**	**72.33**	**83.65**	**72.33**	**75.16**
Total Cost	**310.51**	**272.85**	**289.61**	**264.38**	**284.34**

FX-B-L-W Rotation **Dark Brown Soil Zone ($/ha)**

Cost Item	Flax	Barley	Lentil	Wheat	Rotation
Seed	14.70	16.43	46.70	17.77	23.90
Fertilizer N	38.84	35.24	0.00	30.09	26.04
Fertilizer P	15.20	13.08	7.60	14.41	12.57
Fertilizer S	0.00	0.00	0.00	0.00	0.00
Pesticides	62.52	51.74	99.90	52.24	66.60
Fuel	16.61	14.53	16.61	14.53	15.57
Machine Repair	18.53	15.44	22.98	15.44	18.10
Custom Work & Hired Labor	10.50	10.50	7.41	12.97	10.35
Crop Insurance	4.13	5.51	14.01	4.30	6.99
Utilities& Miscel	10.60	10.60	10.60	10.60	10.60
Interest	4.89	4.55	6.28	4.62	5.09
Transport (Farm to Elevator)	14.78	24.05	6.78	5.77	12.85
Total Variable	**211.30**	**201.67**	**238.87**	**182.74**	**208.65**
Building Repair	2.97	2.97	2.97	2.97	2.97
Property Taxes	11.69	11.69	11.69	11.69	11.69
Insurance & Licenses	4.47	4.47	4.47	4.47	4.47
Machine & Building Dep. & Inv.	53.20	53.20	64.52	53.20	56.03
Total Other Costs	**72.33**	**72.33**	**83.65**	**72.33**	**75.16**
Total Cost	**283.63**	**274.00**	**322.52**	**255.07**	**283.81**

d) Personnel

Name	Months Involved
David Wall	6 months

e) Equipment: None purchased with ADF Funds.

f) Project Development Materials: N/A

g) Project Photos: N/A

h) Acknowledgement: Project support from ADF will be acknowledged on all publications resulting form this investigation. See attachment for ADF acknowledged publication.